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Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm or Individual name	James L. Wolfe, Esq. Ganz Law, P.C.
Signature	James L. Wolfe
Date	October 16, 2003

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of

Frank D. D'Amelio, et al.

Serial No.: 09/384,926

Filed: August 26, 1999

For: MEDICAL IMAGING INSTRUMENTS, SYSTEMS AND METHODS

Date: October 16, 2003

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Karina Ganz
Date of Deposit: October 16, 2003

approved
11/6/03

SUBMISSION OF SUBSTITUTE SPECIFICATION

The Examiner has requested that Applicants provide a substitute specification due to the extensive Preliminary Amendment filed with the application. In response, Applicants submit both a clean copy and a marked-up copy of the specification showing changes from the Preliminary Amendment and to correct minor errors. No new matter has been entered.

CONCLUSION

Applicant submits that in view of the foregoing amendments, the application is in condition for allowance, and favorable action is respectfully requested. The Commissioner is

hereby authorized to charge any fees, including extension fees, which may be required, or credit any overpayments, to Deposit Account No. 50-1001.

Respectfully submitted,

Date: October 16, 2003

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MEDICAL IMAGING INSTRUMENTS, SYSTEMS AND METHODS

With a Video Signal Compensator

A video signal compensator and method for compensating for differential picture brightness of an optical image due to uneven illumination is shown. The video signal compensator includes a device for generating a compensating signal substantially representing at least one parameter of a compensating waveform required to produce a video signal representing an optical image having a substantially uniform brightness. An adder operatively coupled to the compensating signal generating device and a video signal adds the compensating signal and the video signal to produce a compensating video signal used as an input to a video signal processor adjusting its gain both vertically and horizontally compensated by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference compensating the video signal to represent an optical image having a substantially uniform brightness. The compensating signal can be generated by either an analog signal generating device or a digital signal processing device.

B

MEDICAL IMAGING INSTRUMENTS, SYSTEMS AND METHODS
With a Video Signal Compensator

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of pending application number 09/228,773, filed January 11, 1999, which is a divisional of application number 08/791,637, filed January 31, 1997, now abandoned.

1. Field of the Invention

This invention relates to medical instruments, systems and methods and, more particularly, to medical instruments, systems and methods for use in imaging a site in a medical procedure.

2. Description of the Prior Art

A wide variety of optical instruments are used to generate optical images. In the medical field, endoscopes are used in performing surgical procedures, such as minimally invasive surgery, to generate optical images from within a body cavity. In the industrial field, borescopes are used to inspect interior spaces, such as the interior stage of a jet engine, which are generally inaccessible. Other optical instruments are used for performing such routine tasks as inspecting interiors of sewer lines, ventilation systems, pipe lines and other elongated cavities.

Typically, such optical instruments have a video camera operatively coupled to the proximal end thereof to receive the optical image and to produce a video signal of the optical image. The video signal is typically processed by a video signal processor to generate a video output signal used to produce an output image displayed by a video monitor, printed by a printing and/or stored by a video storage device.

It is also known in the art that a video sensor may be integral with the proximal end of an optical instrument. The output of the video sensor in such an instrument is typically applied to a

video signal processor which processes the video signal to produce a video output signal which is applied to a video monitor. One example of such an instrument is a Video Operating Laparoscope offered for sale and sold by ACMI Corporation, the assignee of the present invention.

It is also well known in the art that body cavities, hidden or inaccessible spaces and elongated cavities are either dark or have such low light levels that it is difficult for optical instruments to produce an optical image that can be satisfactorily imaged by a video camera or video sensor.

In order to overcome these problems, a wide variety of light sources have been developed to produce light energy at light levels that provide sufficiently high light levels of illumination in the body cavities, hidden or inaccessible spaces and elongated cavities. A sufficiently high light level enables the optical instruments to produce an optical image of the operative site and to transmit the optical image to the proximal end of the optical instrument enabling the optical image to be imaged by the video camera or video sensor.

In order to accomplish the above, the optical instruments typically include a light guide, such as for example a fiber optic light guide, to transmit light energy from a light source through the proximal end of and through the instrument to the distal end thereof. The light energy is used to illuminate the operative site or area subject to inspection. The optical image is then transmitted by an optical image transferring system from the distal end of and through the instrument to the proximal end thereof where the optical image is directed on the video camera or video sensor.

It is also known in the art that the endoscope may have an illumination source located at the distal end of the endoscope. One of the known prior art laparoscopes had a light bulb located at the distal end of the laparoscope wherein electrical conductors extending from the distal end to the proximal end of the laparoscope energized the light bulb to illuminate the operative site or area subject to inspection. Illumination from the light bulb located at the distal end of the endoscope produced uneven illumination due to the characteristics of the light energy emanating from the light bulb.

It is also known in the art to locate a video sensor, such as a CCD chip, on the distal end of an optical instrument. Such a structure eliminates the use of an optical image transferring system or member. However, such optical instruments still require a light guide to transmit light energy from a light source to the distal end thereof to illuminate the operative site or area subject to inspection. Electrical conductors located within the optical instrument transmit the video signal from the distal tip of and through the instrument to a video signal processor.

It has been observed that when an optical instrument is used in combination with a light guide, or distally located illumination source, the resulting optical image from the optical instrument has differential picture brightness due to uneven illumination at the distal end thereof.

Differential picture brightness tends to take different forms. For example, a typical medical endoscope, having a fiber optic light guide, have diameters generally in the order of about 5 mm to about 10 mm or larger at the distal end. Such endoscopes generally produce an optical image that is brighter in the center and dim on the periphery or edge. In smaller diameter endoscopes having a fiber optical light guide, for example endoscopes having a diameter at the distal end of less that 5 mm, the optical image may be saturated at the center. As yet another example, differential picture brightness may arise due to deficient alignment of the illumination with the site/area being imaged. In this latter form, differential picture brightness is typically characterized by a bright portion toward one side of the picture, decreasing brightness with disposition toward the picture's other side and a dark or black crescent or other portion of the picture adjacent that other side's periphery. In any form, differential picture brightness is characterized by spatial differences (particularly, observable differences) in brightness, e.g., from one picture edge, through the picture center, to an opposite picture edge or otherwise across or among spatial components of the picture.

One known design approach to solve the differential picture brightness problem is to modify the structure and characteristics of the light guide, the optical image transferring system or member or modify both in an attempt to obtain a more uniform brightness e.g., by reducing spatial differences of the optical image developed by the optical instrument itself.

The fiber optic light guides and optics of the optical image transferring systems have been optimized, but, however, the differential picture brightness problem still persists.

The primary cause for the differential picture brightness problem has now been identified to be other than the optical instrument. It has now been identified that it is the light source itself which generates a light energy or light radiation having a peaked characteristic curve with a bright spot in the center thereof and a dim periphery or edge. When the light source is operatively coupled to the light guide, e.g. the fiber optic light guide in an endoscope, the transmitted light energy retains the characteristics of the light source; namely, a bright spot in the center thereof and a dim periphery or edge. In essence, each optical instrument reproduces the characteristic curve of the light source and this results in an optical image having a differential picture brightness due to uneven or non--uniform illumination.

Unsuccessful attempts have been made to design or modify the light source to reduce or eliminate the above described deficiencies.

In addition to the above and as is well known in the art, variations in the operating characteristics of the video sensor or video camera generating the video signals representing optical images introduce shading into the video signal. The combination of the light source problems and shading problems have resulted in poor quality optical images which, in turn, produce poor quality electronic optical images.

It is known in the prior art that vidicon tube cameras, such as for example, a Sony video tube cameras, have used a shading circuit to compensate for the variations in the operating characteristics of the vidicon tube itself (the "Sony Vidicon Shading Circuit"). The Sony Vidicon Shading Circuit used a parabolic waveform and a sawtooth waveform to generate a compensating signal which adjusts the video signal as required to overcome the variations of the vidicon tube operating characteristics.

United States Patent 5,343,302 purports to disclose a video camera which includes a correction circuit in which a parabolic wave signal is generated and the level thereof is adjusted in

accordance with the zoom and iris settings of the camera's optical system. After adjustment, the parabolic wave signal is clipped in accordance with a reference level and the clipped parabolic wave signal is used for correcting the shading of the camera's image signal. The clipping of the parabolic correction signal allows for a more accurate shading correction. The shading correction circuit performs the shading corrections principally in the case of the reduction of the light intensity ratio from the periphery to the center of the image caused by aperture eclipse and in the case of f-drop (i.e. reduction of the f-number) at the telephoto lens setting.

United States Patent 5,157,497 purports to disclose a method and apparatus for detecting and compensating for white shading errors in a digitized video signal using a flat white calibration target. The system includes an inspecting portion for inspecting the amplitude of the output of the pixels which are part of the video image when the image is that of a flat white calibration target, a calculator portion for calculating for each pixel inspected a white shading correction coefficient, and a correction portion for correcting pixels in subsequent video images based on the white shading correction coefficients calculated by the calculator portion.

United States Patent 5,053,879 purports to disclose a method and device for shading correction used in a video printer comprising a TV camera for providing image data of a subject to be printed and an exposure CRT for displaying the image data thereon and to which photographic paper is exposed to make a video printout of the subject. In carrying out the shading correction method, the shading correction device employs a memory for storing the shading correction data, a frame memory for storing image data of a subject to be printed and a device for adding the shading correction data read out from the memory and the image data readout from the memory.

United States Patent 4,979,042 purports to disclose apparatus for correcting shading effects in video images for a document retrieval system. The document retrieval system captures an image of a document in electronic form using linear CCD imagers or a CCD array. The apparatus reduces the size of the memory required to store, correction information by defining the two dimensional non-uniformity characteristics in terms of two functions that are orthogonal. The

orthogonal correction functions are stored in separate memories. During a scan, a pixel counter addresses the X memory while a line counter addresses a Y memory. The correction factors thus obtained are applied sequentially to correct the pixel data value at the current X and Y coordinates. The sources of non-uniformity which are corrected by the apparatus include use of the lens having non-uniformities which are generally known in the optical art as the "cos" law (sometimes known as the cosine law) to focus the image onto the capturing device and, the CCD pixel sensitivity variations and spot uniformities that may occur in an illumination source such as a lamp filament.

The above-identified references indicate approaches directed to correction of shading associated with inherent deficiencies in either/both the imaging performance of video cameras/sensors and such cameras' optics. As previously described, other known approaches are directed to optimizing light sources and guides. Notwithstanding these approaches, alone or together, differential picture brightness remains a problem in acquired images of interior spaces due to illumination deficiencies.

Differential picture brightness due to illumination deficiencies remains a particularly significant problem in the medical field wherein a patient's health typically is at stake. As an example, the success or failure of laparoscopic surgery may depend in substantial part on the quality at which the operative site is imaged for the surgery team.

Accordingly, there is a need for medical imaging instruments, apparatus and methods that address illumination deficiencies, particularly uneven illumination of the operative site/inspection area.

SUMMARY OF THE INVENTION

A novel, new and unique compensating apparatus or video signal compensator for compensating differential picture brightness of an optical image due to uneven illumination is disclosed and taught by this invention. The compensating apparatus or video signal compensator includes a device for generating a compensating signal substantially representing at least one

parameter of a compensating waveform required for the differential picture brightness of an optical image to produce a signal representing an optical image having a substantially uniform brightness. An adder is operatively coupled to the compensating video signal generating device and a video signal for adding the compensating signal and the video signal to produce a compensated video signal, or for using the compensating signal to an input to a video signal processor adjusting its gain both vertically and horizontally by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference. The compensated video signal represents an image having a substantially uniform brightness.

In addition, a new novel and unique method for compensating for differential picture brightness of an optical image due to uneven illumination is discloses and taught by this invention. The method comprises the steps of: (a) generating with a compensating signal device a compensating signal substantially representing at least one parameter of a compensating waveform required for the differential picture brightness of an optical image to produce a video signal representing an optical image having a substantially uniform brightness; and (b) adding with an adder operatively coupled to the compensating signal generating device and a video signal the compensating signal and the video signal to produce a compensating video signal used as an input to a video signal processor adjusting its gain both vertically and horizontally compensated by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference compensating the video signal to represent an optical image having a substantially uniform brightness.

In the preferred embodiment of the apparatus and method of the present invention, the differential picture brightness of an optical image is brighter at its center than at its periphery or edges. Thus, the compensating video signal is used to adjust the gain of the video signal processor both vertically and horizontally by increasing the gain of the video signal in response to a

sawtooth waveform representing the periphery or edges of the optical image and reducing the gain of the video signal in response to the parabolic waveform representing the center of the optical image compensating the video signal to represent an optical image having a substantially flat brightness.

In the Sony Vidicon Shading Circuit, the sawtooth wave generator and parabolic wave generator were used to generate a compensating signal to correct for the deficiencies introduced into or added into the video signal by the vidicon tube itself. The Sony Vidicon Shading Circuit was not used to correct for differential picture brightness of an optical image due to uneven illumination from an optical instrument imaged onto a vidicon tube or sensor.

The correction circuit of United States Patent 5,343,302 generated a parabolic wave signal and the level thereof was adjusted in accordance with the zoom and iris settings of the camera's optical system. Further, the parabolic wave signal of the correction circuit of united states Patent 5,343,302 was clipped to perform shading corrections principally in the case of the reduction of the light intensity ratio from the periphery to the center of the image caused by aperture eclipse and in the case of f-drop (i.e. reduction of the f-number) at the telephoto lens setting. The correction circuit of United States Patent 5,343,302 was not used to correct for, nor does the correction

circuit therein disclose, suggest or teach compensating for differential picture brightness of an optical image from an optical instrument imaged onto video camera or sensor.

The method and apparatus of United States Patent 5,157,497 detects and compensates for white shading errors in a digitized video signal using, a flat white calibration target. The method and apparatus of United States Patent 5,157,497 was based on use of a flat white calibration target and was not used to correct for differential picture brightness of an optical image from an optical instrument imaged onto video camera or sensor.

The shading correction device disclosed in United States Patent 5,053,879 is used for a video printer and employs a memory for storing the shading correction data, a frame memory for storing image date of a subject to be printed and a device for adding the shading correction data

read out from the memory and the image data readout from the memory. The shading correction device of United States Patent 5,053,879 is based on adding shading correction data read out from the memory with the image data readout from the memory. United States Patent 5,053,879 does not disclose, teach or suggest correcting for differential picture brightness of an optical image having uneven illumination from an optical instrument imaged onto video camera or sensor.

The apparatus and method disclosed in United States Patents 4,979,598 and 4,979,042 disclose and teach correction of shading effects in video images for a document retrieval system. The document retrieval system capture an image of a document in electronic form using linear CCD imagers or a CCD array. The apparatus defines the two dimensional non-uniformity characteristics in terms of two functions that are orthogonal about orthogonal axes. The sources of non-uniformity which are corrected by the apparatus compensate for lens deficiencies, the CCD pixel sensitivity variations and spot non-uniformities that may occur in an illumination source such as a lamp filament. The apparatus and method disclosed in United States Patents 4,979,598 and 4,979,042 do not teach, disclose or suggest compensating differential picture brightness of an optical image due to uneven illumination from an endoscope imaged onto a video camera.

The prior art does not disclose, teach or suggest compensating video images for the non-uniform characteristics of a light source located at or transmitted by a light guide to the distal end of an optical instrument to illuminate an operative site or inspection area.

The apparatus and method of the present invention overcomes several of the problems of the prior art including compensating for differential picture brightness due primarily to the non-uniform characteristics of a light source or a light source operatively coupled to a light guide for illumination of an operative site or inspection area. The light energy is typically reflected from the surface of the operative site or inspection area. The reflected light energy and optical image developed therefrom in an optical instrument include the non-uniformities or unevenness of the light energy.

One advantage of the present invention is that the compensation correction apparatus and

method can be used for medical images developed form a variety of optical instruments including endoscopes having an optical image imaged onto a video sensor or video camera.

Another advantage of the present invention is that the amount and shape required for compensation correction can be adjusted as required or an approximation thereof can be provided with adjustable wave shaping devices or circuits.

Another advantage of the present invention is that optical instruments developing an optical image having differential picture illumination with an uneven light return path and light and dark areas which are imaged onto a video sensor or video camera can have the so produced optical images compensated electronically such that the brightness of the areas is more uniform or flat.

Another advantage of the present invention is that a sampling circuit or sensing circuit may be used to determine the correction required for appropriate compensation or an approximation thereof and such circuits can be used with adjustable wave shaping devices or circuits.

Another advantage of the present invention is that a the light returned from the cosine angle of the reflecting surface can be sampled or sensed and a correction based thereon can be developed and applied to video amplifiers to reduce the gain in the bright areas and increase the gain in the dark areas to produce a video signal representing an optical image having substantially even field illumination.

Another advantage of the present invention is that the compensating signal required for making the corrections and the means for applying the compensating signal may be analog, digital or other means, e.g., a hybrid of analog and digital.

Another advantage of the present invention is that a video signal compensator can produce corrections wherein the differential picture brightness of an optical image is brighter at its center than at its periphery or edges. The video signal compensator includes an adder which adds a sawtooth waveform, a parabolic waveform and a video signal to produce a compensating signal used as an input to video signal processor adjusting a its gain both vertically and horizontally by increasing the gain of the video signal in response the sawtooth waveform representing the

periphery of the optical image and reducing the gain of the video signal in response to the parabolic waveform representing the center of the optical image compensating the video signal to represent an optical image having a substantially flat brightness.

Another advantage of the present invention is that a video signal compensator can produce corrections wherein the differential picture brightness of an optical image is brighter at its periphery or edges than at its center. The video signal compensator includes an adder which adds a sawtooth waveform, a parabolic waveform and a video signal to produce a video compensating signal used as an input to a video signal processor adjusting its gain both vertically and horizontally by decreasing the gain of the video signal in response the sawtooth waveform representing the periphery of the optical image and increasing the gain of the video signal in response to the parabolic waveform representing the center of the optical image compensating the video signal to represent an optical image having a substantially flat brightness.

Another advantage of the present invention is that a video signal compensator can include a control device operatively coupled to an adder to increase the brightness of the output video signal to a level which is greater than the average of the differential brightness of the optical image due to the uneven illumination.

Another advantage of the present invention is that a video signal compensator can be used for compensating differential picture brightness of an optical image due to uneven illumination from an endoscope imaged onto a video sensor or video camera.

Another advantage of the present invention is that a method for compensating for differential picture brightness of an optical image due to uneven illumination using a video signal compensator is shown.

Another advantage of the present invention is that a method for compensating for an uneven light path in an endoscope or other optical instrument is shown. The method for compensating can be used to compensate for non-uniformities of the optical system alone or in combination with an illumination system having non-uniformities as used in television viewing

systems.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages of this invention will be apparent from the following description of the preferred embodiment of the invention when considered with the illustrations and accompanying drawings which include the following Figures:

Fig. 1 is a front, top and left end perspective view of a endoscope in the form of a laparoscope having a video camera operatively coupled to an eyepiece located at the proximal end thereof for practicing this invention;

Fig. 2 is a partial top plan sectional view showing the proximal end of another embodiment of a laparoscope having a video sensor directly operatively attached thereto for practicing this invention;

Fig. 3 is a distal section perspective view of on embodiment of a laparoscope of Fig. 1 showing the distal tip having a transparent member for passing an optical image, the location of the fiber optic light guide around the periphery of the laparoscope and two nozzles for directing fluid across the exterior surface of the transparent member;

Fig. 4 is a distal end elevational view showing another embodiment of a laparoscope having a single nozzle for directing fluid across the exterior surface of the transparent member and the location of the fiber optic light guide around the periphery of the laparoscope and nozzle;

Fig. 5 is a distal end elevational view of yet another embodiment of Fig. 4 showing an additional working channel and orientation of the fiber optic light guide;

Fig. 6-is a distal end elevational view of yet another embodiment of Fig. 5 having a fourth channel and orientation of the fiber optic light guide;

Fig. 7 is a distal end elevational view of yet another embodiment of a laparoscope having a nozzle, an irrigation flow orifice, which could be utilized as a first working channel, and an accessory or working channel which is larger that the first channel and which is adapted to pass

working accessories and orientation of a fiber optic light guide;

Fig. 8 is block diagram of an analog video camera having a video signal compensator located between a preamplifier and video signal processor;

Fig. 9 is a block diagram of a digital video camera having a preamplifier, digital-to-analog converter, digital signal processing, and an analog-to-digital converter including a video signal processor located after the analog-to-digital converter;

Fig. 10 is a block diagram of another embodiment of a digital video camera having a preamplifier, video signal compensator, digital-to-analog converter, digital signal processor, analog-to-digital converter and an output device, and an output device, and illustrating that the video signal processor is located before the analog-to-digital converter;

Fig. 11 is a block diagram of another embodiment of a analog video camera having a video sensor, preamplifier, analog video signal processor, video signal compensator and an output device, and illustrating that the video signal compensator is located after the analog video signal processor;

Figs. 12(a) and 12(b) show, respectively: (i) a video signal representing an optical image having differential picture brightness and (ii) a compensated video signal representing an optical image having substantially uniform brightness.

Figs. 13(a) and 13(b) are pictorial representations of respectively: (i) an optical image wherein the center is brighter than a reference level and the periphery is less bright than a reference level and (ii) an optical image wherein the center is less bright than a reference level and the periphery is brighter than a reference level;

Fig. 14 is a pictorial representation of a compensated video signal of an optical image having a substantially uniform brightness;

Figs. 15(a), 15(b) and 15(c) show, respectively, a waveform of a sawtooth wave generator having an increasing slope, a waveform of a sawtooth wave generator having an decreasing slope

and a waveform of a parabolic wave generator having controlled amplitude and orientation;

Fig. 16 is a schematic diagram of the preferred embodiment of a video signal compensator of the present invention adapted to be located in a video camera at a location illustrated in Fig. 8;

Fig. 17 is a block diagram of a digital video camera having a digital storage device for storing a digital representation of the video signal having differential brightness due to uneven illumination; and

Fig. 18 is a block diagram of a digital video camera having a digital storage device for storing a digital representation of the video signal and an 8 x 8 pixel multiplexer/processor for producing a compensated analog video output signal;

Fig. 19 is a waveform of a video signal from a small diameter endoscope illustrating the noise before and after the video signal representing the picture information;

Fig. 20 is a waveform of a video signal from a small diameter endoscope illustrating the action of a sensing device for sensing and removing the noise before and after the video signal representing the picture information; and

Fig. 21 is a block diagram of a sensing device for sensing and removing the noise of Fig. 19 which sensing device, in the preferred embodiment, is in the form of a blanking circuit.

Fig. 22 is a high level block diagram of a medical imaging instrument or system, in accordance with the invention.

DETAILED DESCRIPTION

Before commencing with the detailed description of the preferred and other embodiments of the present invention, the following review will provide a better understanding of the application and utility of the present invention to optical instruments or optical devices which are used to produce an optical image directed onto or imaged onto a video sensor or camera. As an example, the following review will provide background to advance understanding of the application and utility of the present invention in medical imaging instruments, apparatus and methods. The background

is directed particularly to video applications, wherein the invention is directed to enhance real-time motion signals (e.g., frame by frame).

Video cameras used with optical instruments for medical and industrial applications generally are known as an "analog video camera", a "digital video camera" or a "digitally controlled video camera".

In an analog video camera, the video sensor is typically separated from a video signal processor which is sometimes referred to as the video camera. The output of a video sensor (e.g., a CCD) is an analog signal which is applied to a preamplifier. The output of the preamplifier is operatively connected to a remotely disposed video signal processor either directly by electrical conductors or indirectly by a wireless device such as an infrared transmitter and receiver. The output of the video signal processor is an analog video signal in a preselected format, e.g., NTSC, Y/C, RGB or other format. All signal transmission and processing is accomplished using analog techniques.

In a digital video camera, the video sensor is again typically separated from the video signal processor. The output of a CCD is an analog signal which is applied to a preamplifier. The output of the preamplifier is operatively connected by an analog-to-digital converter to a remotely disposed digital signal processor. The output of the digital signal processor is applied to a digital-to-analog converter wherein the output thereof is an analog video signal in a preselected format, e.g., NTSC, Y/C, RGB or other format.

It is also envisioned that the preselected format, encoding scheme or standard television system encoding format could be the PAL format, SECAM format or any other format utilized in a country as a standard of that country. In addition, the format could be a proprietary format for use in a closed circuit television system. The use of either the term "NTSC, Y/C, RGB or other format," or the term "format" alone in appropriate context" is intended to all cover of such preselected formats of output video signals.

In a digitally controlled video camera, the video sensor, preamplifier and remotely disposed

video signal processor are substantially operationally the same as the analog videocamera. However, a digital system controls the operation of each of the components and controls transfer of signals between components, all under control of a digitally programmed devices. However, the output of the video camera is an analog video signal in a preselected format, e.g., NTSC, Y/C, RGB or other format.

Each of the above-described video cameras, as well as other video cameras, are expressly contemplated within the scope of the invention. Moreover, the video sensors of such cameras may be variously implemented without departing from the principles of the invention. The term "video sensor" as used herein is intended to collectively and broadly refer to any video sensor, including solid state sensors and tube-based sensors, including, as non-exhaustive examples, line sensors, area sensors, CCDs, CMOS sensors and other photodiode/photoconductor arrays, as well as vidicon and orthicon tubes and combinations of same. The term "video sensor" includes sensors located at the proximal end of the optical instrument, such as an endoscope. Also, the term "video sensor" is intended to cover all such sensors located at a different location in the optical instrument, such as (a) sensor located at the distal tip of an endoscope, or (b) a sensor video camera, the camera being operatively attached to a medical instrument (e.g., an endoscope) or other optical device wherein an optical image developed by the medical instrument or optical device, having an illumination provided from a light source or a light guide, is imaged onto the video sensor.

Referring now to Fig. 1, Fig. 1 illustrates the preferred application for using the teachings of the present invention in an endoscope. Fig. 1 illustrates an instrument, generally as 30, which is an endoscope in the form of a laparoscope for medical surgery. The instrument 30 includes a housing 32 (e.g., a rigid sheath tube) having a selected length and a distal section or end 36 and a proximal section or end 38. The distal end 36 terminates in a distal tip shown generally as 44. The interior of the laparoscope includes an optical image transferring structure. The optical image transferring means structure may be variously implemented, including as a system or member, but typically

comprises a lens system including relay lenses. In any case, the optical image transferring structure provides for transferring an optical image from the distal tip 44 (through the housing 32) to the proximal end 38 of the laparoscope. Although the elongate housing 32 is generally referred to herein as being rigid, it is understood that the housing and, in turn, the instrument 30 may be other than rigid (e.g., flexible or semi-flexible), without departing from the principles of the invention.

The proximal end 38 of the laparoscope is operatively connected to an extension member shown generally as 48. The extension member 48 includes structure to support a light post 52 and structure to define openings or ports for two channels, which openings are shown as 54 and 60 (60 being visible in Fig. 2). Valves, which in the preferred embodiment are trumpet valves 58 and 62, are operatively connected to openings 54 and 60 respectively. An eyepiece housing, shown generally as 64, terminates in an eyepiece 66 which permits a surgeon to view the optical image transferred through the laparoscope. However, in Fig. 1, a video sensor, typically a CCD sensor and preamplifier, shown generally as 68, is operatively connected to the eyepiece to convert the optical image into a video signal. The video signal is ultimately processed by a video signal processor (such as processor 134 of Fig. 8) to produce a video image on a monitor or video signals for storage of the video image on magnetic tape or other storage device, or for printing the image, or for other purposes.

The laparoscope 30 may include a plurality of channels which can be used for a number of functions. Several species or embodiments of laparoscopes are disclosed herein in Figs. 1 through 7 to show that the present invention can be used with a wide variety of endoscopes or optical instruments.

Fig. 2 shows the proximal end of another embodiment of a laparoscope 30 having a video sensor housing, shown generally as 64', which is adapted to have a video sensor 68' directly operatively attached thereto for practicing this invention. In addition, Fig. 2 illustrates pictorially that a light source 67 is operatively coupled to the light post 52. The light post 52 is operatively

connected to a fiber optic light guide 72 in Fig. 4. The fiber "optic light guide transmits the light energy from the light post 52 located at the proximal end 38 of the laparoscope 30, housing 32 to the distal section or end 36. The light energy is then is directed onto the operative site or inspection area to illuminate the same. (Hereinafter, the operative site and inspection area are sometimes referred to, alone or together, as the "target site".)

Typically the light sources are metal halide, xenon light sources or other similar devices. The light energy from the light source 67 is in the form of a light beam or radiation beam that has defined spatial distribution characteristics which generally includes that center thereof has higher brightness than the periphery or edges thereof. The light energy is applied to the fiber optic light guide, or light guide in other optical instruments, through a light post or equivalent device such as a coupling lens or cone system. The light energy typically is white, visible light; however, it is to be recognized that the light energy may include frequency components outside the visible light spectrum, either supplemental to or in substitution for some or all of the white light frequencies. Examples include infrared and x-ray radiation.

The fiber optic light guide, as well as the other light guides, transmits the light energy and retains the defined spatial distribution characteristics of the light energy. The light energy is directed onto the operative site or inspection area to illuminate the same. The reflected light returned from the cosine angle of the reflecting surface is transmitted by the optical image transferring system to the proximal end of the optical instrument 30 where the optical image having the differential picture brightness developed by the spatial distribution characteristics of the light energy, is imaged on the video sensor 68'. In the alternative, the optical image can be sampled or sensed, using digital sampling and measuring techniques which are well known in the arc, and a correction or compensating signal based thereon can be developed and applied to video amplifiers to reduce the gain in the bright areas and/or increase the gain in the dark areas to produce a video signal representing an optical image having substantially even field illumination.

In Fig. 2, the fiber optic light guide used for illumination of the operative site or inspection

area can be varied in structure as illustrated in the embodiments of Figs. 4 through 7 as described herein below. However, the non-uniform characteristics of a light source 67 are transmitted through the light guide in the optical instrument to the distal end to illuminate the operative site or inspection area which produces the optical image having a differential picture brightness due to uneven illumination.

Fig. 3 shows another embodiment of a distal end of a laparoscope utilizing the teachings of the present invention. In the embodiment of Fig. 3, the distal tip 44 includes structure which are located within the housing 32 for defining at the distal end 36 a mechanism for directing a fluid flow across the exterior surface of an image passing device 76. Image passing device 76 including the distal end of the optical image transferring system or member is located in the center of an aperture 74. In Fig. 3, the image passing device comprises one or more of a distal lens, a window or transparent surface for or of a CCD sensor (or other video sensor), fiber optics, or the like. In Fig. 3, the mechanism for directing fluid flow across the exterior surface comprises a nozzle 80. The nozzle 80 is located in the space 70. In Figure 3, the mechanism that directs fluid flow across the exterior surface of the image passing device also comprises a second nozzle 82, such nozzle being located in the space 70 at a selected distance from nozzle 80. Such mechanism may comprise any selected number of nozzles 80, 82 and/or other selected structure.

Fig. 4 shows yet another embodiment of a laparoscope having a nozzle 80 and irrigation channel 86. Specifically, the distal end 44 of the laparoscope includes an image passing device 76 which is located in the aperture opening 74. In Fig. 4, the nozzle 80 which is located in space 70 directs a fluid flow across the exterior surface of the image passing device 76 and irrigation channel 86 functions as an irrigation orifice. Of course, such a nozzle is not required to practice this invention, but keeping the image passing device clear of image impeding material substantially improves the quality of the optical image passed by the endoscope.

The fiber optic light guide 72 typically comprises one or more light fibers, bundled or otherwise. The light fibers forming the fiber optic light guide 72 are arranged in plural bundles, the

bundles being disposed in space 70. Typically, as shown, the bundles of light fibers are located around the optical image transferring system or member and are positioned around the various orifices and nozzles as depicted in Fig. 4.

Fig. 5 illustrates the structure of a distal end of a laparoscope similar to that illustrated in Fig. 4 with the addition of a third channel 90 which can be used for other purposes during surgery, such as for example as an aspiration orifice.

Fig. 6 illustrates the structure of yet another distal end of a laparoscope similar to that illustrated in Fig. 5 with the addition of a fourth channel 92. Channels 86, 90 and 92 are equally spaced around the optical image transferring system or member. As in Fig. 4, the light fibers forming the fiber optic light guide 72 are located around the optical image transferring system or member and are positioned around the various orifices and nozzles.

Fig. 7 illustrates yet another embodiment of a laparoscope wherein the distal end 44 has a different structure than the structures of Fig. 3 through 6. One difference is that the image passing device 76 is off center relative to the elongated sheath tube 32. As such, the aperture opening 74 is off center relative to the elongated axes 102, but is coaxial with the central axis 100 of the image passing device 76. As a result of the offset of the axes100 end 102, an expanded space shown generally as 110 is provided between the housing 32 and the optical image transferring member located within the laparoscope. A working channel 96 is provided in the expanded space 110. The light fibers forming the fiber optic light guide 72 are located around the optical image transferring member and are positioned around the various orifices, nozzles and working channels.

In each of the structures of the distal ends of endoscopes illustrated by Figs. 2 through 7, the fiber optic light guide 72 directs the light energy out of the distal end and, in each embodiment, the light energy retains the non-uniformity of or unevenness in illumination of the light source, e.g., light source 67 as shown in Fig. 2. Of importance, as is described further hereinafter, a video signal compensator are operative with any of the optical images developed by the endoscopes illustrated in Figs. 1 through 7 so as to produce a video signal representing an optical image having

substantially uniform brightness, notwithstanding the light guide's directing of non-uniform or uneven illumination.

In the alternative, the fiber optic light guide 72 could be eliminated and electrical conductors could be extended through the endoscope to a light bulb or other light source located at the distal end. As an example, the light bulb or other light source could be located in the position shown by working channel 96 in Fig. 7. (The light bulb, light source, light guide and other structure associated with illuminating a target site are sometimes referred to herein, individually, collectively and grouped, as an "illuminator'.)

Fig. 8 illustrates a preferred embodiment of an analog video camera for practicing this invention. An optical image having differential picture brightness due to uneven or non-uniform illumination (the term "uneven illumination" being used to describe this characteristic) is illustrated by arrow 118. The optical image having differential picture brightness due to uneven illumination 118 is imaged directly or indirectly onto a video sensor 120. The output from the video sensor is an analog video signal which is applied to a preamplifier 122.

The video sensor 120 and preamplifier 122 are generally located with or operatively attached to the optical instrument as described in connection with Figs. 1 and 2. In such event, electrical conductors 126, which are operatively connected to the preamplifier 122, extend from the proximal end of a laparoscope to a remotely disposed video signal processing apparatus depicted by dashed box 128. The video signal processing apparatus 128 includes a video signal compensator 130 (the video signal compensator is sometimes referred to herein as a "compensating apparatus").

The video signal compensator 130 performs the function of generating a compensating signal which is used to compensate the video signal representing the optical image having differential picture brightness due to uneven illumination 118. The output signal of the video signal compensator 130, as provided on output 132, is applied as an input to a standard analog video

signal processor 134 which processes video signals to produce an analog signal in a preselected format, e.g., NTSC, Y/C , RGB or other format.

The output from the video signal processor 134, appearing on output 136, is a formatted video signal compensated to represent the optical image having substantially uniform brightness. The compensated video signal on output 136 is applied to an output device depicted by box 138. (Hereinafter, the term "output device" contemplates, without limitation, display devices (e.g., flat panel display technology, light valve technology, tube technology or otherwise), printing devices, storage devices (e.g., CD, DVD or other optical or magneto-optical storage, VCR, RAID, hard drive, or other analog/digital, temporary/semi-permanent/permanent storage), networking devices and other similar devices.)

As shown in Figure 8, the video signal compensator 130 is located between the preamplifier 122 and the video signal processor 134. The advantages of locating the video signal compensator 130 in this position is that the video signal is in analog format as it is generated by the video sensor. The preamplifier generally performs the function of providing sufficient amplification of the analog video signal to drive the electrical conductors with the analog video signal so as to deliver an amplified video signal to the remote video signal processing apparatus 128. Another advantage is that the amplified video signal and the compensating signal can be added multiplied, mixed, interpolated, extrapolated or otherwise applied together before or at the front end to the video signal processor such that the video signal processor outputs a formatted, compensated video signal.

As is readily apparent to anyone of skill in the art, the compensating signal may be variously applied to the video signal. As an example, the compensating signal may be applied within the video signal processor 134. To do so, the video signal processor 134 has applied, as inputs, the compensating signal and the amplified video signal, each via output 132. The so-input amplified video signal, in such case, is passed through the video signal compensator 130. In such case, the video signal processor 134 may apply the compensating signal so as to control the

processing (e.g., the gain) of the video signal, or it may add, multiply, mix, interpolate, extrapolate or otherwise process the compensating signal with the video signal. As another example, the video signal compensator 130 generates the compensating signal and applies that compensating signal with the video signal, so as to output to the video signal processor 134 a compensated video signal for formatting. The application is implemented by adding, multiplying, mixing, interpolating, extrapolating or otherwise applying together the compensating signal and the video signal.

The compensator 130 may be variously implemented in generating the compensating signal. As an example, the compensator 130 can be implemented to generate the compensating signal from components of the video signal. These components typically include one or more, or combinations of: timing components, synchronization components, and test, marker or other references embedded in the video signal (e.g., in the content portion thereof). Use of embedded references engenders advantages, including enabling the system to recognize and track changes in the orientation of the endoscope. Such changes, which typically arise from manipulations related to the applicable medical procedures and which include rotation about the endoscope's elongate axis, tend to result in variations in illumination, including changes in differential picture brightness. If the differential picture brightness characteristics are the same, but merely rotated or otherwise re-oriented, the tracking enable the compensation to be adapted thereto.

However, it is also possible to add multiply, mix, interpolate, extrapolate, or otherwise apply together the amplified video signal and the compensating signal after processing of the video signal to a preselected format. For example, Fig. 9 illustrates a typical digital video camera. In Fig. 9, the optical image having differential picture brightness due to uneven illumination 118 is imaged directly or indirectly onto a video sensor 120. The output from the video sensor is an analog video signal which is applied to a preamplifier 122 as described above relative to Fig. 8.

The amplified video signal appearing on conductors 126 is applied to an analog-to-digital converter 142, the output of which is a digitized video signal representing the optical image having differential picture brightness due to uneven illumination. The output of the analog-to-digital

converter 142 is applied to a digital signal processor 146 where the output signal is a processed digital video signal representing the optical image having differential picture brightness due to uneven illumination. The output of the digital signal processor 146 is applied to a digital-to-analog converter 150, the output of which is an analog signal in a standard or preselected format, such as an NTSC, Y/C, RGB or other format video signal. A video signal compensator 154, utilizing the teachings of this invention, produces a compensating signal in the preselected format which is added, multiplied, mixed, interpolated, extrapolated or otherwise applied with the video signal output by the digital-to-analog converter 150, so as to produce a formatted, compensated video signal representing an optical image having substantially uniform brightness. As an example, the video signal compensator 154 generates the compensating signal and applies that compensating signal with the video signal. The application is implemented by adding, multiplying, mixing, interpolating, extrapolating or otherwise processing together the compensating signal and the video signal. The compensated video signal appearing on output 156 is applied to a monitor, video storage device, printer or other output device depicted by box 158.

The compensating signal may also be otherwise introduced. Figs. 10 and 11 discussed below are exemplary.

In Fig. 10, the compensating signal is produced before digital processing of the video signal. For example, Fig. 10 illustrates a digital video camera wherein the optical image having differential picture brightness due to uneven illumination 118 is imaged directly or indirectly onto a video sensor 120. The output from the video sensor is an analog video signal which is applied to a preamplifier 122 as described above relative to Fig. 8.

The amplified video signal from the preamplifier 122 is applied to video signal compensator 160, the output of which is an analog compensated video signal representing the optical image having substantially uniform brightness. The output of the video signal compensator 160 is applied to an analog-to-digital converter 161 wherein the output is a digital signal that is applied to a digital signal processor 162. The output of the digital signal processor 162 is a digitized, formatted

compensated video signal which is applied to a digital-to-analog converter 163. The output of the digital-to-analog converter 163 is a formatted analog video signal representing the optical image having substantially uniform brightness. The output of the digital-to-analog converter 163 is applied to a monitor, video storage device, printer or other output device depicted by box 164.

As described, the digital signal processor 162 has applied, as an input, the compensated video signal output from the video signal compensator 160. To do so, the compensator 160 adds, multiplies, mixes, interpolates, extrapolates or otherwise applies the compensating signal with the amplified video signal. In the alternative, the compensator 160 generates the compensating signal and passes through the amplified video signal, both as inputs to the analog-to-digital converter 161. In the latter case, either the analog-to-digital converter 161 or the digital signal processor 162 applies the respective signals to produce the compensated video signal.

Fig. 11 illustrates another embodiment of a typical analog video camera having a video signal compensator located after the analog video signal processor. In Fig. 11, the optical image 118 having differential picture brightness due to uneven illumination 118 is imaged directly or indirectly onto a video sensor 120. The output from the video sensor 120 is an analog video signal which is applied to a preamplifier 122 as described above relative to Fig. 8.

The amplified video signal from the preamplifier 122 is applied to an analog video signal processor 165. The output from the analog video signal processor 165 is applied to a video signal compensator 166 so as to output a formatted, compensated video signal representing the optical image having substantially uniform brightness. The output of the video signal compensator 166 is in a standard or preselected format, such as an NTSC, Y/C, RGB or other format video signal. The video signal compensator 166, utilizing the teachings of this invention, produces a compensating signal (e.g., in or responsive to the preselected format) which is added, multiplied, mixed, interpolated, extrapolated or otherwise applied with the formatted video signal, so as to produce the formatted, compensated video signal. The compensated output signal from the video signal compensator 166 is applied to a monitor, video storage device, printer or other output device

depicted by box 168.

It is envisioned that the video signal compensator could be implemented at numerous locations in the video signal circuit path, or integral with the video signal processor (whether analog or digital).

Figure 12(a) is a graph of a video signal depicted by waveform 171 representing a optical image having differential picture brightness due to uneven illumination. A reference line 170 is depicted which represents an optical image having substantially uniform brightness. The portion shown as 171 of the waveform 170 represents that part of the optical image 118 which is less bright than the optical image represented by the reference line 170, and the portion shown as 174 shows that part of the optical image 118 which, at its peak, is brighter than the optical image represented by the reference line 170.

Figure 12(b) is a graph of the compensated video signal depicted by waveform 178 representing the optical image of Fig. 12(a) having substantially uniform brightness. The compensated video signal of waveform 178 is generated by conditioning the waveform 171. In this illustration, the waveform 178 is generated by conditioning the waveform 171 with one or more compensating signals so that (a) the amplitudes of the portion 174 of waveform 171 which are brighter than desired are appropriately decreased to form portion 180 of waveform 178, (b) the amplitudes of the portions 172 of waveform 171 which are less bright than desired are appropriately increased to form portions 180 of waveform 178 and (c) the amplitudes of the portions 172 of waveform 171 which correspond to sites which are expected to be non-illuminated or non-imaged are appropriately decreased to form portions 181 of waveform 178. As such, the waveform 178 corresponds substantially closely at relevant times to the level of the reference line 170, such correspondence reflecting an optical image having substantially uniform illumination.

It is to be recognized that, while Figs. 12(a) and (b) respectively depict a small portion of a video signal and its compensated video signal (e.g., one line of video content for a video frame), the deficiencies and compensation therefor as illustrated therein are applicable to

these signals for the optical image entirely or in any selected part, whether described vertically, horizontally and/or radially, or otherwise. That is, the compensation or other conditioning preferably is directed to ameliorate or correct differential picture brightness spatially.

Fig. 13(a) pictorially represents an optical image having differential, picture brightness. The optical image is brighter at its center 188 than at its periphery 190. The solid portions of lines 192 depict a decreasing brightness of the optical image while the dashed portions of lines 192 depict acceleration in the decrease of brightness toward the optical image's periphery 190. The shaded portion about the optical image's center 188 indicate brightness (uniform or otherwise) that exceeds a desirable level.

Fig. 13(b) pictorially represents an optical image having differential picture brightness. The optical image is brighter at its periphery 196 than at its center 188. The solid portions of lines 200 depict a decreasing brightness of the optical image while the dashed portions of lines 200 depict acceleration in the decrease of brightness toward the optical image's center 198.

It is to be understood that, although Figs. 13(a) and 13(b) depict radially symmetric brightness functions (e.g., brightness levels vary but the variations are consistent among radii, with such variations being functions of disposition along a radius and not the radius' angle), such symmetry may be absent in practice. That is, brightness may be anywhere from less symmetric to partly or wholly asymmetric, including by varying either/both by radial disposition and angle. In addition, brightness may be characterized by variations in either/both horizontal and vertical dimensions associated with the optical image.

Fig. 14 is a pictorial representation of a line 204 representing the top portion of an envelope of a compensated video signal plotting the intensity as a function of distance "S" from the axis of the image 206. As shown by the line 204, the compensated video signal is amplified by a controlled device such as a controlled gain amplifier or variable gain amplifier to increase the brightness of the output video signal to a level which is greater than the average of the differential brightness of the optical image due to the uneven illumination.

Before describing the operation of the schematic diagram of Fig. 16 (which is an embodiment of the video signal compensator 134 illustrated in Fig. 8), the following discussion relates to compensating waveforms that associated with the video signal compensator. Although only sawtooth and parabolic waveforms are discussed in the following descriptions, it is recognized that either or both of these waveforms may be omitted, and that any number and variety of other waveforms may be employed (alone or in combinations with the sawtooth and/or parabolic waveforms), without departing from the principles of the invention. As an example, such other and combinations of waveforms may be employed when the differential picture brightness is characterized by partly or wholly asymmetry. As another example, the waveforms may be preset, so as, e.g., to correlate to and correct known deficiencies associated with medical imaging instruments and systems. As to this latter example, the preset waveforms preferably are brought into operation either manually or automatically, (e.g., by detection of the imaging instrument or one or more components of a system.

The video signal compensator comprises a device for generating a compensating signal substantially representing at least one parameter of a compensating waveform required for addressing differential picture brightness of an optical image toward producing a video signal representing an optical image having substantially uniform brightness. In the schematic diagram of Fig. 16, the video signal compensator is an analog signal generating device.

The video signal compensator includes a sawtooth wave generator for generating a sawtooth waveform having a predetermined rising slope and a sawtooth wave generator for generating a sawtooth waveform having a predetermined falling slope. The sawtooth wave generators described, as well as selected additional sawtooth wave generators, may be integral, grouped or separate, without departing from the principles of the invention.

Fig. 15(a) is a sawtooth waveform 210 having a predetermined rising slope and a controlled amplitude. Fig. 15(b) is a sawtooth waveform 212 having a predetermined falling slope and a controlled amplitude.

The video signal compensator also includes a parabolic wave generator for generating a parabolic waveform having a controlled amplitude and orientation. Plural parabolic wave generators may be provided, whether integral, grouped or separate, without departing from the principles of the invention.

Fig. 15 (c) is a parabolic waveform 214 having a controlled amplitude and orientation. If the orientation of the parabolic waveform is reversed, it is referred to as an "inverted parabolic waveform."

The amplitude and slope of each sawtooth waveform and the amplitude and the orientation of each parabolic waveform are adjusted to generate an acceptable compensating signal. In operation, a typical implementation of a video signal compensator provides an analog signal adder operatively coupled to the sawtooth wave generator and the parabolic wave generator adds the sawtooth waveforms and the parabolic waveform to produce a compensating signal. The compensating signal is used to compensate the video signal representing the optical image having differential picture brightness due to uneven illumination.

Referring now to the schematic, diagram of Fig. 16, the circuit is based on the use of two (2) quad operating amplifiers. In operation, the horizontal synchronizing signals of the composite video signal are applied to lead 220 and inverted by amplifier 224. If the horizontal synchronizing signals of the composite video signal are of proper polarity, then inversion of the signals will not be necessary. The output of amplifier 224 is applied as an input to amplifier 226 which is used as the sawtooth wave generator to generate a sawtooth waveform in the form of sawtooth waveform 210 of Fig. 15(a) having a predetermined rising slope and a controlled amplitude. The output of the sawtooth wave generator 226 applies the sawtooth waveform to lead 230 which forms one side of a sawtooth waveform balance network 236. The output of the balance network 236 is adjusted as required to produce an acceptable balance using the sawtooth waveform by the variable pot, variable resistor or potentiometer depicted as balance network 236. The output from balance network 236 appears on lead 252.

In addition, the output of the sawtooth wave generator 226 applies the sawtooth waveform to lead 240 which is an input to amplifier 244. Amplifier 244, which essentially functions as a sawtooth wave inverter, inverts the sawtooth waveform having a predetermined rising slope and a controlled amplitude to generate a sawtooth waveform having a predetermined falling slope and controlled amplitude in the form of sawtooth waveform 212 of Fig. 15(b). The output of the amplifier 244 applies the sawtooth waveform to lead 250 which forms the other side of the sawtooth waveform balance network 236.

The output of the amplifier 244 is applied to input 254 of an amplifier 256 which functions as a parabolic wave generator. Amplifier 256 produces as an output a parabolic waveform in the form of parabolic waveform 214 of Fig. 15(c) having a controlled amplitude and orientation. In the preferred embodiment, the parabolic waveform is an inverted parabolic waveform.

Lead 252, which is the output of the balance network 236 is operatively connected to a summation terminal 260 which is an analog adder. The balance or mix of the sawtooth waveforms received by inputs 230 and 250, respectively, are controlled by the adjustment of the balance network 236. In addition, the output of the amplifier 256, which functions as a parabolic wave generator, applies the parabolic waveform having a controlled amplitude and orientation to the summation terminal 260, to produce the horizontal component of the compensating signal.

The vertical portion of the compensating signal is generated as follows. The vertical synchronizing signals of the composite video signal are applied to lead 270 and inverted by amplifier 272. If the vertical synchronizing signals of the composite video signal are of proper polarity, then inversion of the signals will not be necessary. The output of amplifier 272 is an input to amplifier 274 which is used as the sawtooth wave generator to generate a sawtooth waveform in the form of sawtooth waveform 210 of Fig. 15(a). The output of the sawtooth wave generator 274 applies the sawtooth waveform to lead 280 which forms one side of a sawtooth waveform balance network 286. The output of the balance network 286 is similarly adjusted by the variable pot, variable resistor or potentiometer, which output appears on lead 302.

In addition, the output of the sawtooth wave generator 274 applies the sawtooth waveform to lead 290 of an amplifier, 294. Amplifier 294, which essentially functions as a sawtooth wave inverter, inverts the sawtooth waveform having a predetermined rising slope and a controlled amplitude to generate a sawtooth waveform having a predetermined falling slope and controlled amplitude in the form of sawtooth waveform 212 of Fig. 15(b). The output of the amplifier 294, which also functions as a sawtooth wave inverter, applies the sawtooth waveform to lead 300 which forms the other side of the sawtooth waveform balance network 286.

The output of the amplifier 294 is applied to input 304 of an amplifier 306 which functions as a parabolic wave generator.

Amplifier 306 produces as an output a parabolic waveform having a controlled amplitude and orientation in the form of parabolic waveform 214 of Fig. 15(c). In the preferred embodiment, the parabolic waveform is an inverted parabolic waveform.

Lead 302, which is the output of the balance network 286, is operatively connected to a summation terminal 310 which is an analog adder. The balance or mix of the sawtooth waveforms received by inputs 280 and 300, respectively, are controlled by the adjustment of the balance network 286. In addition, the output of the amplifier 306, which functions as a parabolic wave generator, applies the parabolic waveform having a controlled amplitude and orientation to the summation terminal 310, or analog adder, to produce the vertical component of the compensating signal.

The horizontal portion of the compensating signal appearing on the summation terminal 260 and the vertical portion of the compensating signal appearing on the summation terminal 260 are applied to summation terminal 316 which produces the compensating signal required to compensate the video signal toward such video signal representing an optical image having substantially uniform brightness. The compensating signal appearing on summation terminal 316 is applied as an input to controlled gain amplifier 330 which amplifies the compensating signal to a selected level.

Amplifier 340 is unused. The output of the controlled gain amplifier 330 has a high impedance relative to the video signal to be compensated in the video signal processor, illustrated as 134 in Fig. 8. Therefore, the output of the amplifier 330 is applied to input 332 of a video driver 334 which produces a compensating signal on output 336 at a low impedance. Output 336 is then applied to the preamplifier stage of the video signal processor 134 of Fig. 8 as is well known to a person skilled in the art. Typically, an adder or other component in the video signal processor 134 is used to add, multiply, mix, interpolate, extrapolate or otherwise apply together the compensating signal and video signal to produce the compensated video signal.

Based on the above description, it is readily apparent that the video signal compensator is a device for generating a compensating signal substantially representing at least one parameter of a compensating waveform facilitating production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from a video signal representing an optical image having differential picture brightness. For example, if one of a sawtooth wave generator and a parabolic wave generator was used to practice the teachings of this invention, a compensating signal would be generated which compensates the video Signal to represent an optical image having decreased differential picture brightness (i.e., increased uniformity in brightness). In a preferred embodiment, both the sawtooth waveforms and the parabolic waveform are used to produce the compensating signal.

As described above, the compensating signal typically is added, multiplied, mixed, interpolated, extrapolated or otherwise applied with the video signal to produce a compensated video signal. The video signal processing apparatus 128 preferably is responsive to the compensating signal by adjusting gain both vertically and horizontally, e.g., by increasing the gain applicable to the video signal representing that part of the optical image which is less bright than a reference level and/or, e.g., by reducing the gain of the video signal representing that part of the optical image which is brighter than the same or another reference level and, thereby, compensating the video signal to represent an optical image having a substantially uniform

brightness.

It is understood that the compensated video signal may be subject to processing in addition to formatting. As an example, the compensated video signal may be processed to remove artifacts. It also may be processed so as to respond to signal saturation, as might occur when, during a medical procedure, a reflective medical instrument enters a portion of the target site characterized by an enhanced gain via a compensating signal. In that event, the enhanced gain typically would be reduced and, preferably, that reduction would be implemented on a dynamic basis.

In a typical case, an optical image is brighter at its center than at its periphery. The video signal compensator, implemented according to Figure 16, adds, multiplies, mixes, interpolates, extrapolates or otherwise applies together one or more sawtooth waveforms and the parabolic waveform (and, in some embodiments, the video signal or portion(s) thereof), such waveforms being properly balanced and otherwise calibrated, to produce a compensating signal. The compensating signal typically is employed within the video signal compensator or is applied as an input to a video signal processor. So employed or applied, the compensating signal preferably adjusts the gain applicable to the video signal, e.g., both vertically and horizontally. This is accomplished, typically, by increasing the gain applied to the video signal in to the sawtooth waveform representing the periphery of the optical image and by reducing the gain applied to the video signal in response to the parabolic waveform representing the center of the optical image, resulting in the video signal representing an optical image having a substantially flat brightness.

In another typical case, wherein an optical image is brighter at its periphery than at its center, the video signal compensator typically adds, multiplies, mixes, interpolates, extrapolates or otherwise applies together one or more sawtooth waveforms and the parabolic waveform (and, in some embodiments, the video signal or portion(s) thereof), such waveforms being properly balanced and otherwise calibrated, to produce a compensating signal. The compensating signal typically is employed within the video signal compensator or is applied as an input to a video signal

processor together the video signal so as to produce a compensated video signal. The compensating signal, so employed or applied, preferably adjusts the gain of the video signal, e.g., both vertically and horizontally. This is accomplished by decreasing the gain applied to the video signal in response the sawtooth waveform representing the periphery of the optical image and by increasing the gain applied to the video signal in response to the parabolic waveform representing the center of the optical image, resulting in said video signal representing an optical image having a substantially flat brightness.

Figures 1 through 16 disclose the elements or components of a preferred embodiment of a system for practicing this invention. The system includes an endoscope 30 having a proximal end 38 and a distal end 36. A light guide 72 is located within the endoscope and extends from the proximal end 38 to the distal end 36 of the endoscope 30. The light guide 72 has a light post 52 at its proximal end which is adapted to receive light energy from a light source 67 and to transmit the light energy from its distal end to illuminate a target site.

In the alternative, the light guide 72 could be eliminated and an illumination source such as a light bulb could be located directly at the distal end 36 of the endoscope 30.

The endoscope includes an optical image transferring member, which includes, in one embodiment, image passing device 76 and which extends from the proximal end 38 to the distal end 36 of the endoscope. A light source 67 is operatively connected to the light post 52 to apply light energy to the light guide 72. A video sensor 68 is operatively coupled to the proximal end of the endoscope 30 for imaging an optical image having differential picture brightness due to uneven illumination.

A compensating apparatus is operatively coupled to the video sensor and typically includes a sawtooth wave generator for generating a sawtooth waveform having a predetermined rising slope and/or a predetermined falling slope, and a controlled amplitude. In addition, the compensating apparatus includes a parabolic wave generator for generating a parabolic waveform having a controlled amplitude and orientation. Typically, an adder is operatively coupled to the

sawtooth wave generator and the parabolic wave generator for adding the sawtooth waveform and the parabolic waveform to produce a compensating signal which is used as to adjust the gain applied to the video signal, e.g., both vertically and horizontally. This is accomplished by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference, thereby compensating the video signal to represent an image having a substantially uniform brightness.

In the embodiment of Fig. 17, an optical image having differential picture brightness due to uneven illumination 398 is imaged directly or indirectly onto a video sensor 400 (e.g., in the form of a CCD). The output from the video sensor 400 is an analog video signal which is applied to a preamplifier 402. The preamplified video signal is applied to an analog-to-digital converter 406. The video signal compensator in this embodiment is a part of a digital signal processing device shown by dashed box 410.

The digital signal processing device 410 includes a digital storage device 414 (e.g., in the form of a freeze frame) a digital representation of the video signal having the differential brightness due to uneven illumination as received from the analog-to-digital converter 406. Concurrently, the digital video signal from the analog-to-digital converter 406 is applied to a digital signal processor 416 for digitally processing the digital signal representation of the video signal. The digital processor 416 produces a digital compensating signal representing at least one parameter of a compensating waveform facilitating production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from a video signal representing an optical image having differential picture brightness. The digital signal processor 416 digitally calculates the components of the compensating signal using a sawtooth waveform reference and a parabolic waveform reference in a process analogous to that of the analog process described above. The output from the digital signal processor 416 is a compensating signal in analog format having an illumination signal Y_o and color signal C_O. Illumination signal Y_o

appears on lead 424 and color signal C_O appears on lead 426.

The video signal is stored in the digital storage device 414 for a predetermined period of time and is applied to a digital-to-analog converter 420. The output from the digital-to-analog converter 420 is the analog video signal representing the optical image 398 delayed by a predetermined time period. The output from the digital-to-analog converter 420 appears on output 430.

The illumination signal Y_o on lead 424 is applied as an input to first adder 434. The color signal C_O on lead 426 is applied as an input to a second adder 438. The delayed uncompensated analog video signal on output 430 is applied to each of the first adder 434 and second adder 438.

The analog output from the first adder 434 is in the form of a compensated illumination signal Y_m which appears on output lead 440. The analog output from the second adder 438 is in the form of a compensated color signal C_m which appears on output lead 442. These output signals represent the Optical image having substantially uniform brightness and is applied to an output device, such as that shown by 138 in Fig. 8.

In an alternative embodiment, the structures of Figure 17 may be otherwise operated to produce a compensated video signal. Such embodiment contemplates a learning mode and an operating mode. In the learning mode, the freeze frame 414 receives a video signal for characterizing the differential picture brightness. The freeze frame 414 processes the learning-mode video signal so as to identify digital compensation coefficients for each pixel of the frame. As an example, the coefficients may be calculated, as follows: a) determine a reference brightness for the learning mode frame(s) (e.g., an average brightness value across all or part of the frame, a median brightness value across all or part of the frame or otherwise) and b) dividing, for each pixel, the reference brightness by the pixel's actual brightness for the learning mode frame(s).

In a preferred embodiment, the learning mode provides for detection of flawed or otherwise unacceptable results from the learning mode. In the event of such detection, the learning mode preferably supports one or more default compensations. Such default compensations may be

variously implemented. Example implementations include: a) generating digital compensation coefficients that comprise a best fit (e.g., based on the learning mode data that appears to be without substantial flaws, at least to a threshold confidence); b) employing a previous set of compensation coefficients (e.g., as to all or as to part or parts of the optical image); c) bypassing compensation (e.g., as to all or as to part or parts of the optical image); and d) a combination of implementations, including of those implementation not listed above (e.g., selecting among previous sets of compensation coefficients to find a best fit and, if the best fit is deemed unacceptable, implementing a bypass).

In the operating mode, the compensation coefficients are processed via the DAC 420 to generate an analog compensating signal. Concurrently, the DSP receives a digital video signal from the ADC 406. The DSP processes the digital video signal and, via a digital-to-analog functionality, produces an analog illumination signal Y_o on lead 424 and an analog color signal C_o on lead 426. The compensating signal is applied (via adding, multiplying, mixing, interpolating, extrapolating or otherwise) with the illumination signal Y_o and with the color signal C_o, respectively at application components 434, 438. The application components 434, 438 produce compensated video signal, this signal comprising compensated illumination signal Y_m (on output lead 440) and compensated color signal C_m (on output lead 442).

Although Fig. 17 shows only one compensating signal, it is understood that more than one compensating signal may be generated. In particular, it is contemplated that separate compensating signals may be generated toward compensating, respectively, the illumination signal Y_o and the color signal C_o. Moreover, although Figure 17 shows compensation as to Y/C formatted video signals, it is understood that compensation may be applied to a video signal or signal of other formats. As examples, the compensation may be applied to composite video signals, color differential signals, RGB video signals, NTSC, PAL, SECAM or any other format, along or in combination(s).

In the embodiment of Fig. 18, the initial components are the same as described in Fig. 17 and include the optical image having differential picture brightness, due to uneven illumination 398 being imaged directly or indirectly onto a video sensor 400. The output from the video sensor 400 is an analog video signal which is applied to a preamplifier 402. The preamplified video signal is applied to an analog-to-digital converter 406. The video signal compensator in this embodiment is a part of a digital signal processing device shown by dashed box 410'. The digital signal processing device 410' produces a compensating signal representing at least one parameter of a compensating waveform facilitating production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from the video signal representing an optical image having differential picture brightness.

At this point, the embodiment of Fig. 18 differs from that of Fig. 17. In the embodiment of Fig. 18, the digital signal processing device 410' includes a digital storage device 414 (e.g., in the form of a freeze frame) for storing a digital representation of the video signal having differential brightness due to uneven illumination received from the analog-to-digital converter 406. Concurrently, the digital video signal from the analog-to-digital converter 406 is applied to an 8 x 8 pixel matrix multiplexer/processor 450.

The video signal is stored in the digital storage device 414 for a predetermined period of time to enable the 8 x 8 pixel matrix multiplexer/processor 450 to digitally calculate the components of the compensating signal using a sawtooth waveform reference and a parabolic waveform reference in a process analogous to that of the analog process described above. The 8 x 8 pixel matrix multiplexer/processor 450 analyzes the brightness level of the optical image represented by the video signal on a bit-by-bit basis against a brightness reference to determine a compensating signal for the horizontal and vertical components thereof. The output of the 8 x 8 pixel matrix multiplexer/processor is a digital signal.

The output from the digital storage device 414 is applied to the 8 x 8 pixel matrix multiplexer/processor 450 where the digital video signal is compensated with the compensating

signal generated by the 8 x 8 pixel matrix multiplexer/processor 450.

The output from the 8 x 8 pixel matrix multiplexer/processor 450 is applied to the digital signal processor 416 which produces a compensated analog video signal representing the optical image having substantially uniform brightness. The digital techniques for performing this analysis are well known to persons skilled in the art.

In the embodiment illustrated in Fig. 18, the analog output from the digital signal processor 416 is in the form of a compensated illumination signal Y_m which appears on output lead 452 and a color signal C_m which appears on output lead 454. It is to be understood that, while the color signal may remain uncompensated, the color signal typically is also compensated.

In an alternative embodiment, the structures of Figure 18 may be otherwise operated to produce a compensated video signal. Such embodiment contemplates a learning mode and an operating mode. In the learning mode, the freeze frame 414 receives a video signal for characterizing the differential picture brightness. The freeze frame 414 processes the learning-mode video signal so as to identify digital compensation coefficients for each pixel of the frame. The coefficients may be calculated as described above for the alternative embodiment based on Figure 17.

In a preferred embodiment, the learning mode provides for detection of flawed or otherwise unacceptable results from the learning mode. In the event of such detection, the learning mode preferably supports one or more default compensations. Such default compensations may be variously implemented. Example implementations include: a) generating digital compensation coefficients that comprise a best fit (e.g., based on the learning mode data that appears to be without substantial flaws, at least to a threshold confidence); b) employing a previous set of compensation coefficients (e.g., as to all or as to part or parts of the optical image); c) bypassing compensation (e.g., as to all or as to part or parts of the optical image); d) detecting pixels having sensitivity defects (e.g., individual pixels having hyper-, hypo- or no sensitivity), whether of individual or group(s) of pixels, so as to interpolate, extrapolate or otherwise treat such pixels

isolated from other compensation (or other conditioning), and e) a combination of implementations, including of those implementation not listed above (e.g., selecting among previous sets of compensation coefficients to find a best fit and, if the best fit is deemed unacceptable, implementing a bypass).

In the operating mode, the pixel matrix multiplexer/processor 450 receives a digital video signal from the ADC 406. The multiplexer/processor 450 also receives the digital compensation coefficients from the freeze frame 414, which coefficients serve as a compensating signal in the digital domain. The multiplexer/processor 450 digitally adds, multiplies, mixes, interpolates, extrapolates or otherwise applies the coefficients to the video signal. As such, the multiplexer/processor 450 produces a compensated digital video signal which signal is applied to the DSP 416. The DSP formats the video signal so as to output compensated illumination signal Y_m (on output lead 452) and compensated color signal C_m (on output lead 454).

As to implementations supporting learning modes, it is recognized that, various advantages attach. As an example, such implementations tend to enhance correction of asymmetrical differential brightness. As another example, such implementations tend to enhance correction of dynamic variations in differential brightness, such as those that may result from rotation of an endoscope during a procedure. As yet another example, such implementations tend to enhance correction of variations in differential brightness developing over time, e.g., from the deteriorating performance of the endoscope, any components thereof, and/or any components of the system, including one or more illuminators.

In smaller diameter endoscopes having a diameter at the distal end on the order of about 5 mm or less, the video signal representing the optical image typically has (a) a waveform 460 illustrated by Fig. 19. In Fig. 19, the waveform 460 has a low level noise portion of the video signal shown as element 462 which appears before the picture information portion 464 of the video signal and (b) a low level noise portion of the video signal shown as element 466 which appears after the

picture information portion 464. These low level noise portions 462, 466 of the video signal 460 can be monitored by a sensing device for sensing and removing the noise to improve the video signal.

Fig. 20 illustrates a waveform 470 of the video signal from a small diameter endoscope illustrating the effects of the sensing device for sensing and removing the noise before and after picture information portion 474 of the video signal. In Fig. 20, the portions of the signal shown as 472 and 474, respectively before and after the picture information portion 474, have the noise removed therefrom. The picture information portion 474 is substantially the same as the picture information portion 464 of Fig. 19.

In a preferred embodiment, the sensing device for sensing and removing the noise is in the form of a blanking circuit 480 as illustrated by Fig. 21. The signal appearing on input 482 to the blanking circuit 480 is essentially in the form of the waveform 460 shown in Fig. 19. The signal appearing on the output 484 of the blanking circuit is essentially in the form of the waveform 470 shown in Fig. 19. One example of a sensing device that can be used in such a blanking circuit is a Schmitt trigger which requires that a certain threshold voltage level be reached by the video signal before the amplifier receives the input video signal. Of course, any known electrical system or circuit for sensing and removing the noise is envisioned to be within the teachings of this invention.

The present invention includes a method for compensating for differential picture brightness of an optical image due to uneven illumination. The method comprises the steps of: (a) generating with a compensating signal generating device a compensating signal substantially representing at least one parameter of a compensating waveform to facilitate production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from the video signal representing an optical image having differential picture brightness; and (b) adding, multiplying, mixing, interpolating, extrapolating or otherwise applying together with an adder, multiplier, mixer, interpolator, extrapolator or other application component operatively coupled to the compensating signal generating device and a video signal the compensating signal and the video signal to produce a compensated video signal. The compensating signal preferably

is employed to adjust the gain applied to the video signal. As an example, the compensating signal applies both vertically and horizontally by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference, thereby compensating said video signal to represent an optical image having a substantially uniform brightness.

In an application where the differential picture brightness of an optical image is brighter at its center than at its edges, the method produces as an output signal a video signal having its gain both vertically and horizontally compensated by increasing the gain of the video signal in response to the sawtooth waveform representing the edges of the optical image and reducing the gain of the video signal in response to the parabolic waveform representing the center of the optical image, thereby compensating said video signal to represent an optical image having a substantially flat brightness.

In an application where the differential picture brightness of an optical image is brighter at its edges than at its center, the method produces as an output signal a video signal having its gain both vertically and horizontally compensated by decreasing the gain of the video signal in response to the sawtooth waveform representing the edges of the optical image and increasing the gain of the video signal in response to the parabolic waveform representing the center of the optical image, thereby resulting in said video signal representing an optical image having a substantially flat brightness.

Where the method is an analog process, the step of adding, multiplying, mixing, interpolating, extrapolating or otherwise applying may be accomplished using a compensating signal generating device which is an analog signal generating device for generating the compensating signal. Similarly where the method is a digital process, the step of adding, multiplying, mixing, interpolating, extrapolating or otherwise applying may be accomplished using a compensating signal generating device which is an digital signal processing device for generating

the compensating signal.

If it is desired to raise the brightness level of the compensated video signal, the method may further include the step of increasing the brightness associated with the output video signal to a level which is greater than the average of the differential brightness of the optical image due to the uneven illumination. Similarly, the brightness associated with the output video signal may be adjusted (pre- or post-compensation) so as to have a brightness at a selected level below that average, or above or below a reference, or based on some selected calculus. To accomplish this, a control device may be employed, e.g. one operatively coupled to the adder, multiplier, mixer, interpolator, extrapolator or other application component. For impedance matching, the method may further include the step of applying, with a driver amplifier operatively coupled to the adder, the output video signal to a video signal processor at a low impedance.

In a preferred embodiment, the method includes the use of a compensating signal generating device which is an analog signal generating device for generating the compensating signal. The method preferably comprises the steps of: (a) generating with a sawtooth wave generator a sawtooth waveform having at least one of a predetermined rising slope, a predetermined falling slope and a controlled amplitude, (b) generating with a parabolic wave generator a parabolic waveform having a controlled amplitude and. orientation; and (c) adding, multiplying, mixing, interpolating, extrapolating or otherwise applying together, using an analog adder, multiplier, mixer, interpolator, extrapolator or other application component, one or more of the sawtooth and the parabolic waveform (and, in some embodiments, the video signal or portion(s) thereof) to produce the compensated video signal.

Although a preferred embodiment of the present invention is a medical laparoscope having a fiber optic light guide, the video signal compensator can be used with any optical system where a light source having a non-uniform or uneven characteristics is used to illuminate an operative site or inspection area providing an optical image having differential picture brightness due to uneven illumination. The light source may be located intermediate the endoscope or at the distal end of the

endoscope.

It is also envisioned that the teachings of the present invention can be used for industrial applications. For example, borescopes are used to inside the inspect the interior stages of jet engines. Typically, the optical image produced by a borescope is imaged directly on a video camera. The video signal compensator disclosed and taught herein can be used for such industrial applications. Further, persons skilled on the art can identify other applications where the uneven brightness of an optical image can be compensated to produce a substantially uniform brightness level. It is envisioned that this invention can be used for such applications.

Turning to Figure 22, depicted is a high level block diagram of a medical imaging instrument or system 2200, in accordance with the invention. The medical instrument or system 200 comprises illuminators 2212, 2212a, an image acquisition component 2214, an output component 2216 and a conditioning component 2218.

In Figure 22, a target site 2210 is illuminated by illuminator 2212. As previously described, the target site 2210 comprises an operative site and/or an inspection area and the illuminator 2212 comprises one or more of light sources, light guides and the like. The target site 2210, for the purposes of the following description, has an associated target image. A target image is a representation of the target site, the representation being an optical, electronic or other signal, that signal being formatted consistent with signals for driving one or more relevant output devices, photonic devices or interface technologies (the latter terms being defined below).

Generally, the concept of a target image expresses a goal selected for achievement. As an example, in the context of a video display, a target image may be selected that correlates to a display image of the target site, the display image being displayed on a monitor, and wherein a) the target site is illuminated without deficiency (e.g., without unevenness) and b) no other component of the imaging instrument and system (including any video sensor, image transferring structure and monitor) contributes deficiencies in the acquisition, transmittal, processing and display of the image.

The target image generally is associated with selected parameters, qualities and/or characteristics. These parameters, qualities and/or characteristics may extend to the entire image or only to parts thereof (e.g., the target image may comprise a key area that, like a spotlight, draws the attention of the conditioning component). As an example, the target image may be characterized in its omission of differential picture brightness associated with uneven illumination of the target site.

It is understood that a target image may be selected that falls short (and, perhaps, falls substantially short) of being a perfect image of the target site. As an example, the target image may be flawed significantly as to other than the selected parameters, qualities and/or characteristics. As another example, the target image may engender a compromise among one or more parameters, qualities and/or characteristics, with or without a compromise as to one or more other parameters, qualities and/or characteristics (e.g., a best fit).

In a specific case, a target image may be selected to correlate to a display image of the target site wherein the target site is illuminated unevenly. In this case, the target image is selected with attention to parameters, qualities and/or characteristics relevant to target site illumination. Moreover, the target image may or may not be selected with attention to other parameters, qualities and/or characteristics. (Such other parameters, qualities and/or characteristics, if any, otherwise may or may not have --or may be substantially without-- deficiencies.)

So subject to uneven illumination, this case's target image is characterized by differential picture brightness. The differential picture brightness may, however, be trivial in that spatial variations in brightness below a detection threshold are understood to be undetectable to the human eye. The detection threshold is subject to various factors, including factors relating to the output device (e.g., a printer, a display, the presentation area and dot pitch), the video sensor (e.g., its dynamic range), the site illumination (e.g., the intensity and energy distribution), ambient lighting, the quality and aperture of applicable optics (e.g., of an endoscope), the medical

procedure, and the quality of the human eye (specifically or generally), many of which factors are quantifiable through empirical analysis or otherwise.

Accordingly, a target image may be selected which has associated therewith undetectable or detectable differential picture brightness. In the undetectable case, the target image effectively is characterized by the absence of associated differential picture brightness, whether the selected target image correlates to a display image having differential picture brightness at, under or well under the detection threshold. In the detectable case, the target image typically is selected in connection with efforts to reduce differential picture brightness in imaging (i.e., although the flaw remains, it or its impact has been ameliorated). In this latter case, the target image preferably is selected so that the differential picture brightness, while detectable, is acceptable under selected criteria. As an example, the target image may be selected notwithstanding detectable differential picture brightness, provided that flaw is insufficient to impede an applicable medical procedure or otherwise to engender a non-trivial problem in imaging and use.

Moreover, the detectable case explicates the nature of the compensated video signal of previously described camera embodiments. In such embodiments, the cameras produce compensated video signals which video signals represent optical images having substantially uniform brightness, as contrasted with uncompensated video signals representing optical images having differential picture brightness. In such discussions, the term "substantially uniform brightness" generally corresponds to the employ of a target image which itself corresponds to elimination of differential picture brightness, to reduction of differential picture brightness below the detection threshold, or to having a detectable differential picture brightness that, as determined under the circumstances, is acceptable under selected criteria.

While the descriptions above focus on target images that correlate to display images, the correlation may be selected respecting other output devices, photonic devices or interface technologies, with or without a display device. In any case, a target image is a representation of the target site, the representation being an optical, electronic or other signal of appropriate

formatting. The illuminator 2212 may be variously implemented. In a medical instrument such as an endoscope, as previously described, the illuminator 2212 may be disposed internal to the endoscope's housing. At the same time, the illuminator 2212 may be otherwise disposed, including external to the endoscope (in such case, the illuminator 2212 generally may not be considered a component of the instrument). In a medical system, the illuminator 2212 may be implemented so that the illuminator 2212 is integral with the imaging instrument or separate therefrom.

Moreover, plural illuminators 2212 may be employed, as indicated by second illuminator 2212a in Figure 22. In such case, one or more illuminators 2212, 2212a may be integral with the imaging instrument and/or one or more illuminators 2212, 2212a may be external to such instrument, or some combination of integral and external illuminators may be used.

As previously described, the illuminators 2212, 2212a may direct selected illuminating frequencies onto the target site 2210. While white light is typical, it may be supplemented with, or substituted by, other frequencies outside the visible spectrum. These supplemental/substitute frequencies may be variously implemented, particularly when plural illuminators 2212 are employed. The supplemental/substitute frequencies may be variously employed, including, as examples, toward enhancing acquisition, conditioning and/or output of an image (as described below) or toward recognition of the target site, portion(s) thereof and/or anomalies therein (such recognition may also be employed in the enhancing process).

In any case, the illuminators 2212 generally provide deficient illumination. In particular, illuminators 2212 typically subject the target site 2210 to uneven illumination.

The image acquisition component 2214 generates one or more acquired images of the target site. An acquired image may be an optical, electronic (e.g., video) or other signal, or a combination thereof. An acquired image generally results from illumination of the target site 2210, as provided by the illuminators 2212.

The image acquisition component 2214 may be variously implemented. The image acquisition component 2214 typically comprises one or more video sensors, optical image transferring structures, and other mechanical, optical, electronic, opto-mechanical, electro-mechanical, and electro-optical components.

The image acquisition component 2214 may be variously disposed. The disposition depends, among other things, on its implementation and, in some cases, on the implementation of the output component 2216. The disposition also depends on whether the component 2214 is implemented as part of a medical instrument or as part of a medical system. As an example, if the image acquisition component 2214 is implemented as a CCD without an optical image transferring structure, the component 2214 typically is disposed at or adjacent the distal tip of an endoscope, so as to generate a video signal that, via electrical connectors, is provided to either/both the conditioning component 2218 and the output component 2216. As another example, however, if the image acquisition component 2214 is implemented to include a CCD which is disposed away from the endoscope's distal tip or remotely from the endoscope itself, the image acquisition component 2214 typically will be implemented also to include an optical image transferring structure, such structure disposed so as to receive the optical image of the target site and provide that image to the CCD so that the CCD may generate one or more acquired images. (Indeed, in such latter case, the image acquisition component 2214 generates at least two acquired images -- one being an optical signal of the structure and another being an electronic signal from the CCD.)

The output component 2216 generates one or more output images, the output images being available on output 2226. An output image may be an optical, electronic (e.g., video) or other signal, or a combination thereof. The output image preferably correlates to, or achieves substantial correlation to, the target image. As an example, if the target image is selected so as to have differential picture brightness that is undetectable over some portion of an image, the output image preferably achieves undetectability over that entire portion or over substantially all of the portion and, where that undetectability is not achieved respecting that portion, the output image

preferably achieves substantial undetectability. In any case, correlation may be deemed present provided that the agreement of the output image with the target image is sufficient to preclude any significant impediment to the use of the instrument/system/method (including respecting any applicable medical procedure) and does not engender a non-trivial problem in imaging or related thereto.

The output component 2216 is variously implemented. Typically, the output component 2216 comprises a display device (e.g., as previously described, flat panel display technology, light valve technology, tube technology or otherwise), a printing device, a storage device, a networking device or some other output device. The output component 2216 may also comprise one or more optical lenses, lens groups, fiber optics (e.g., a fiber optic bundle having one or more optical fibers), or other photonic device. The output component 2216 may also comprise an interface or other connection technologies (all referred to sometimes hereinafter as "interface technology"), including to or with any one or more of such output devices and/or photonic devices. The output component 2216 may also comprise a combination of output devices, of photonic devices, of interface technology, or any groups of same.

As an example, the output component 2216 may be implemented integrally with an endoscope. The output component 2216 may comprise an interface which directs output images (e.g., as formatted or unformatted video signals) to a remote output or photonic device 2228 (e.g., a display device). In such case, the output/photonic device 2228 typically is considered to be part of the medical system, but not part of the endoscope itself. Moreover, as previously described with respect to Figures 1 and 2, the output component 2216 may be operatively coupled to the endoscope, but considered separate therefrom.

The output component 2216 is variously disposed. The disposition depends, among other things, on its implementation and, in some cases, on the implementation of the image acquisition component 2214. The disposition also depends on whether the component 2216 is implemented as part of a medical instrument or as part of a medical system. As an example, if the output

component 2216 comprises a monitor or a head mounted display, that component 2216 is likely to be disposed remotely from an endoscope. As another example, the output component 2216 may be integral with the endoscope, particularly if implemented as a small display device (e.g., a miniature LCD-on-silicon display and associated optics, all integrated as the endoscope's eyepiece).

The conditioning component 2218 may also be variously implemented. Generally, the conditioning component 2218 provides for selective conditioning of one or more acquired images, one or more output images or one or more intermediate images (such intermediate images typically being derived from acquired and output images) or combinations of same. To illustrate, if the image acquisition component is implemented to generate acquired images comprising optical and electrical signals, the conditioning component generally is implemented so as to provide for selective conditioning of both. Similarly, if the image output component is implemented to generate output images comprising optical and electrical signals, the conditioning component generally is implemented so as to provide for selective conditioning of both. In either such case, it is preferred that the conditioning component provides appropriate conditioning, e.g., conditioning appropriate to the respective image signal and to the respective image output component.

Although the conditioning component may apply conditioning to various images, the conditioning component generally is directed to enhance correlation of the output image to the target image. In a preferred embodiment, the conditioning component selectively reduces differential picture brightness across all or selected portions of the output image. In another preferred embodiment, the target image has an associated energy profile and the conditioning component conditions so as to enhance correlation of the energy profile of the output image to energy profile of the target image. Generally, the conditioning is performed in connection with and to improve performance in an applicable medical procedure.

The conditioning component provides for conditioning by (i) selectively processing all or selected portions of at least one of the acquired image, the output image and the intermediate

image or (ii) selectively controlling at least one the image acquisition component and the image output component. In the first case, the conditioning component generally provides directly for processing of the images, e.g. in the conditioning component itself. As an example, in the above camera embodiments, the conditioning component is sometimes implemented as or within the video signal compensator, which compensator not only generates a compensating signal, but typically applies that signal to the video signal, so as to generate a compensated video signal.

In the second case, the conditioning component provides indirectly for processing. To illustrate, the conditioning component may generate control signals that direct operation of a digital component or may generate analog signals that control (e.g., via gain circuits, active filters, etc.) the performance of other components' processing the applicable acquired, output or intermediate signal. As an example, where the image acquisition component has an acquisition area and has brightness sensitivity that is controllable as a function of acquisition area position, the conditioning component may be implemented to condition the acquired image by selectively controlling the brightness sensitivity of the image acquisition component. In another example, where the image output component has a output space and has brightness sensitivity that is controllable as a function of position in the output space, the conditioning component may be implemented to condition the output image by selectively controlling the brightness sensitivity of the image output component. The output space tends to be particular to the applicable output device, photonic device or interface technology (e.g., an output image that drives a monitor may have an output space correlating to the geometries of the monitor's display area).

It is also understood that the conditioning component may be implemented to provide for conditioning through a combination of such selective processing and controlling.

The conditioning component effectuates such processes or controls via selected signal processing. The signal processing may be conducted in the analog domain, the digital domain or in some combination thereof. The signal processing typically includes one or more of the following: amplification, attenuation, filtering, mixing, adding, multiplying, interpolating,

extrapolating, phase shifting and frequency shifting. The signal processing may be applied to all or selected portions of at least one of the acquired image, the output image and the intermediate image.

Moreover, the signal processing typically varies across the acquired, output and intermediate images. As an example, the signal processing may be directed to increasing the brightness in some parts of an image while decreasing it in others. These increases and decreases may or may not have symmetry, or may have portions of symmetry or asymmetry, across an image.

The conditioning component preferably is responsive to the target image. That is, the conditioning component preferably is implemented to condition the acquired, output and/or intermediate images as to the parameters, qualities and/or characteristics associated with the target image. To do so, the conditioning component typically provides for conditioning based on one or more calibrations (see, e.g., the learning modes of the alternative embodiments described above with reference to Figs. 17 and 18). Such calibration can be variously implemented, particularly in the context of a medical procedures. Example calibrations include: calibration previous to a medical procedure; manual calibration performed one or more times during a medical procedure; automatic calibration performed at regular intervals during the medical procedure; automatic calibration performed at intervals during the medical procedure based on selected triggering events; and dynamic calibration performed during the medical procedure.

Calibration may also be responsive to empirical information relevant to the medical procedure. As an example, calibration may be responsive to the detection threshold associated with differential picture brightness. Accordingly, the calibration may be directed to identify variations in performance relative to the detection threshold (e.g., whether the variations are detectable), and to provide for conditioning based thereon.

The conditioning component 2218 may be variously disposed. The disposition depends on whether the component 2218 is implemented as part of a medical instrument or as part of a

medical system. As an example, the conditioning component 2218 may be integral, in whole or part, with either the image acquisition component 2214 or the image output component 2216. As another example, the conditioning component 2218 may be integral, in whole or part, with both the image acquisition component 2214 and the image output component 2216. In this latter example, the image acquisition component 2214, the image output component 2216, and the conditioning component 2218 may be integrated in a medical imaging instrument, such that the image output component 2216 is an interface technology which connects the medical imaging instrument with, separate from the medical imaging instrument, at least one output device, photonic device and interface technology.

The output component 2216 preferably is coupled with the image acquisition component 2214. Depending on the implementation of the conditioning component 2218, these components 2216, 2214 may be coupled directly (via coupling 2220), indirectly (via the conditioning component 2228), or both. If coupled directly, the output component 2216 preferably receives acquired images via the coupling 2200. If coupled indirectly, the output component 2216 may receive acquired images from the conditioning component 2218 (via coupling 2224), which acquired images may be wholly or partially conditioned, or not conditioned at all. If the acquired images are partially conditioned or not conditioned, the output component 2216 preferably also receives appropriate conditioning signals from the conditioning component 2218, such conditioning signals providing for conditioning of the acquired, output or intermediate images within the output component 2216. Moreover, such conditioning signals may be provided via output 2226 to other output devices/photonic devices/interface technologies, so as to control conditioning of acquired, output and/or intermediate image received or generated therein.

The invention also contemplates a method for use in imaging a target site in a medical procedure. In such method, the target site is subject to deficient illumination. Moreover, the methods responds to the target site having associated therewith a target image, that target image being selected respecting the deficient illumination. The method includes the steps of generating

an acquired image of the target site, generating an output image of the target site, and conditioning at least one of the acquired image, the output image and an intermediate image. The method preferably provides for enhanced correlation of the output image to the target image. In particular, the method provides for conditioning to selectively reduce differential picture brightness across all or selected portions of an output image. The method contemplates operations in either/both the analog and digital domains.

The method contemplates conditioning provided by at least one of (i) selectively processing all or selected portions of at least one of an acquired image, an output image and an intermediate image, (ii) selectively controlling at least one of the generating of an acquired image and the generating of an output image, and (iii) a combination of such processing and controlling. In such processing/controlling, the method contemplates conditioning by providing selectively for at least one of amplification, attenuation, filtering, mixing, adding, multiplying, interpolation, extrapolation, phase shifting and frequency shifting to all or selected portions of at least one of an acquired image, an output image and an intermediate image.

As an example, the method contemplates conditioning by controlling the generating of an acquired image and, in the specific case where an acquisition area has a brightness sensitivity that is controllable as a function of the acquisition area position, by selectively controlling the brightness sensitivity respecting the acquisition area position. As another example, the method contemplates conditioning by controlling the generating of an output image and, specifically in the case where an output space has a brightness sensitivity that is controllable as a function of position in the output space, by selectively controlling the brightness sensitivity respecting the output area position.

Because an acquired image may be generated as an optical signal and/or as an electrical signal, the method contemplates providing conditioning of either of both of these signals. Similarly, because an output image may be generated as an optical signal and/or as an electrical signal, the method contemplates providing conditioning of either of both of these signals.

The method preferably is responsive to the target image. That is, the method preferably is implemented to provide conditioning of the acquired, output and/or intermediate images as to the parameters, qualities and/or characteristics associated with the target image. To do so, the method preferably provides for conditioning based on one or more calibrations (see, e.g., the learning modes of the alternative embodiments described above with reference to Figs. 17 and 18). Such calibrating can be variously implemented, particularly in the context of a medical procedures. Example approaches for calibrating include: calibrating previous to a medical procedure; manually calibrating, in particular performed one or more times during a medical procedure; automatically calibrating, in particular performed at regular intervals during the medical procedure; automatically calibrating, in particular performed at intervals during the medical procedure based on selected triggering events; and dynamically calibrating performed during the medical procedure. Calibrating may also be responsive to empirical information relevant to the medical procedure (e.g., the detection threshold associated with differential picture brightness).

As previously described, the invention also contemplates a medical system wherein the target site is illuminated, at least in part, using frequencies other than visible light. These frequencies may be variously employed, including, as examples, toward enhancing acquisition, conditioning and/or output of an image (as described below) or toward recognition of the target site, portion(s) thereof and/or anomalies therein (such recognition may also be employed in the enhancing process). As examples, the illumination includes ultrasonic radiation and/or electromagnetic radiation in the infrared and/or x-ray spectrums. Based on reflections, absorptions and/or transmissions of that or other such radiation, the image acquisition component preferably generates an acquired image. That acquired image may be in substitution for or supplemental to an acquired image generated from illumination in the visible spectrum. In a particular embodiment, the conditioning component provides for selective conditioning of at least one of an acquired image, an output image and an intermediate image based on the radiation-based acquired. At the

same time, the conditioning component typically conditions on bases other than the radiation-based acquired image.

Persons skilled in the art will recognize the foregoing description and embodiments are not limitations, but examples. It will be recognized by persons skilled in the art that many modifications and variations are possible in the details, materials, and arrangements of the parts and steps which have been described and illustrated in order to explain the nature of this invention, and that such modifications and variations do not depart from the spirit and scope of the teachings and claims contained herein.

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~~A VIDEO SIGNAL COMPENSATOR FOR COMPENSATING DIFFERENTIAL PICTURE BRIGHTNESS OF AN OPTICAL IMAGE DUE TO UNEVEN ILLUMINATION AND METHOD~~

MEDICAL IMAGING INSTRUMENTS, SYSTEMS AND METHODS

A video signal compensator and method for compensating for differential picture brightness of an optical image due to uneven illumination is shown. The video signal compensator includes a device for generating a compensating signal substantially representing at least one parameter of a compensating waveform required to produce a video signal representing an optical image having a substantially uniform brightness. An adder operatively coupled to the compensating signal generating device and a video signal adds the compensating signal and the video signal to produce a compensating video signal used as an input to a video signal processor adjusting its gain both vertically and horizontally compensated by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference compensating the video signal to represent an optical image having a substantially uniform brightness. The compensating signal can be generated by either an analog signal generating device or a digital signal processing device.

~~A VIDEO SIGNAL COMPENSATOR FOR COMPENSATING DIFFERENTIAL PICTURE BRIGHTNESS OF AN OPTICAL IMAGE DUE TO UNEVEN ILLUMINATION AND METHOD~~

MEDICAL IMAGING INSTRUMENTS, SYSTEMS AND METHODS

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of pending application number 09/228,773, filed January 11, 1999, which is a divisional of application number 08/791,637, filed January 31, 1997, now abandoned.

1. Field of the Invention

~~This invention relates to a video signal compensator for compensating a video signal for differential picture brightness of an optical image and more particularly relates to a video signal compensator for compensating a video signal for differential picture brightness of an optical image due to uneven illumination. In the preferred embodiment, the video signal compensator compensates for differential picture brightness of an optical image from an endoscope which is brighter at its center than at its periphery. The optical image from the endoscope is imaged onto a video sensor.~~

This invention relates to medical instruments, systems and methods and, more particularly, to medical instruments, systems and methods for use in imaging a site in a medical procedure.

2. Description of the Prior Art

A wide variety of optical instruments are used to generate optical images. In the medical field, endoscopes are used in performing surgical procedures, such as minimally invasive surgery, to generate optical images from within a body cavity. In the industrial field, borescopes are used to inspect interior spaces, such as the interior stage of a jet engine, which are generally inaccessible. Other optical instruments are used for performing such routine tasks as inspecting interiors of sewer lines, ventilation systems, pipe lines and other elongated cavities.

Typically, such optical instruments have a video camera operatively coupled to the proximal end thereof to receive the optical image and to produce a[[n]] video signal of the optical image. The video signal is typically processed by a video signal processor ~~and displayed on a video monitor or~~ to generate a video output signal used to produce an output image displayed by a video monitor, printed by a printing and/or stored by a video storage device.

It is also known in the art that a video sensor may be integral with the proximal end of an optical instrument. The output of the video sensor in such an instrument is typically applied to a video signal processor which processes the video signal to produce a video output signal which is applied to a video monitor. One example of such an instrument is a Video Operating Laparoscope offered for sale and sold by ~~CIRCON ACMI Division of Circon~~ ACMI Corporation, the assignee of the present invention.

It is also well known in the art that body cavities, hidden or inaccessible spaces and elongated cavities are either dark or have such low light levels that it is difficult for optical instruments to produce an optical image that can be satisfactorily imaged by a video camera or video sensor.

In order to overcome these problems, a wide variety of light sources have been developed to produce light energy at light levels that provide sufficiently high light levels of illumination in the body cavities, hidden or inaccessible spaces and elongated cavities. A sufficiently high light level enables the optical instruments to produce an optical image of the operative site and to transmit

the optical image to the proximal end of the optical instrument enabling the optical image to be imaged by the video camera or video sensor.

In order to accomplish the above, the optical instruments typically include a light guide, such as for example a fiber optic light guide, to transmit light energy from a light source through the proximal end of and through the instrument to the distal end thereof. The light energy is used to illuminate the operative site or area subject to inspection. The optical image is then transmitted by an optical image transferring system from the distal end of and through the instrument to the proximal end thereof where the optical image is directed on the video camera or video sensor.

It is also known in the art that the endoscope may have an illumination source located at the distal end of the endoscope. One of the known prior art laparoscopes had a light bulb located at the distal end of the laparoscope wherein electrical conductors extending from the distal end to the proximal end of the laparoscope energized the light bulb to illuminate the operative site or area subject to inspection. Illumination from the light bulb located at the distal end of the endoscope produced uneven illumination due to the characteristics of the light energy emanating from the light bulb.

It is also known in the art to locate a video sensor, such as a CCD chip, on the distal end of [[a]] an optical instrument. Such a structure eliminates the use of [[a]] an optical image transferring system or member. However, such optical instruments still require a light guide to transmit light energy from a light source to the distal end thereof to illuminate the ~~operating~~ operative site or area subject to inspection. Electrical conductors located within the optical instrument transmit the video signal from the distal tip of and through the instrument to a video signal ~~compensator~~ processor.

It has been observed that when an optical instrument is used in combination with a light guide, or distally located illumination source, the resulting optical image from the optical instrument has differential picture brightness due to uneven illumination at the distal end thereof.

Differential picture brightness tends to take different forms. For example, a typical medical endoscope, having a fiber optic light guide, have diameters generally in the order of about 5 mm to

about 10 mm or larger at the distal end. Such endoscopes generally produce an optical image that is brighter in the center and dim on the periphery or edge. In smaller diameter endoscopes having a fiber optical light guide, for example endoscopes having a diameter at the distal end of less that 5 mm, the optical image may be saturated at the center. As yet another example, differential picture brightness may arise due to deficient alignment of the illumination with the site/area being imaged. In this latter form, differential picture brightness is typically characterized by a bright portion toward one side of the picture, decreasing brightness with disposition toward the picture's other side and a dark or black crescent or other portion of the picture adjacent that other side's periphery. In any form, differential picture brightness is characterized by spatial differences (particularly, observable differences) in brightness, e.g., from one picture edge, through the picture center, to an opposite picture edge or otherwise across or among spatial components of the picture.

One known design approach to solve the differential picture brightness problem is to modify the structure and characteristics of the light guide, the optical image transferring system or member or modify both in an attempt to obtain a more uniform brightness e.g., by reducing spatial differences of the optical image developed by the optical instrument itself.

The fiber optic light guides and optics of the optical image transferring systems have been optimized, but, however, the differential picture brightness problem still persists.

The primary cause for the differential picture brightness problem has now been identified to be other than the optical instrument. It has now been identified that it is the light source itself which generates a light energy or light radiation having a peaked characteristic curve with a bright spot in the center thereof and a dim periphery or edge. When the light source is operatively coupled to the light guide, e.g. the fiber optic light guide in an endoscope, the transmitted light energy retains the characteristics of the light source; namely, a bright spot in the center thereof and a dim periphery or edge. In essence, each optical instrument reproduces the characteristic curve of the light source and this results in an optical image having a differential picture brightness due to uneven or non--uniform illumination.

Unsuccessful attempts have been made to design or modify the light source to reduce or eliminate the above described deficiencies.

In addition to the above and as is well known in the art, variations in the operating characteristics of the video sensor or video camera generating the video signals representing optical images introduce shading into the video signal. The combination of the light source problems and shading problems have resulted in poor quality optical images which, in turn, produce poor quality electronic optical images.

It is known in the prior art that vidicon tube cameras, such as for example, a Sony video tube cameras, have used a shading circuit to compensate for the variations in the operating characteristics of the vidicon tube itself (the "Sony Vidicon Shading Circuit"). The Sony Vidicon Shading Circuit used a parabolic waveform and a sawtooth waveform to generate a compensating signal which adjusts the video signal as required to overcome the variations of the vidicon tube operating characteristics.

United States Patent 5,343,302 ~~discloses~~ purports to disclose a video camera which includes a correction circuit in which a parabolic wave signal is generated and the level thereof is adjusted in accordance with the zoom and iris settings of the camera's optical system. After adjustment, the parabolic wave signal is clipped in accordance with a reference level and the clipped parabolic wave signal is used for correcting the shading of the camera's image signal. The clipping of the parabolic correction signal allows for a more accurate shading correction. The shading correction circuit performs the shading corrections principally in the case of the reduction of the light intensity ratio from the periphery to the center of the image caused by aperture eclipse and in the case of f-drop (i.e. reduction of the f-number) at the telephoto lens setting.

United States Patent 5,157,497 ~~discloses~~ purports to disclose a method and apparatus for detecting and compensating for white shading errors in a digitized video signal using a flat white calibration target. ~~The correction system is capable of automatically determining the amount of white shading correction to be applied to specific video image pixels as well as the application of~~

~~that correction to a digitized video signal.~~ The system includes an inspecting portion for ~~identifying the required correction within a video frame, a calculating portion for computing the amount of correction to be applied to the video signal, and a correction portion for correcting the video signal based upon the correction computed by the calculating portion~~ inspecting the amplitude of the output of the pixels which are part of the video image when the image is that of a flat white calibration target, a calculator portion for calculating for each pixel inspected a white shading correction coefficient, and a correction portion for correcting pixels in subsequent video images based on the white shading correction coefficients calculated by the calculator portion.

United States Patent 5,053,879 ~~discloses~~ purports to disclose a method and device for shading correction used in a video printer comprising a TV camera for providing image data of a subject to be printed and an exposure CRT for displaying the image data thereon and to which photographic paper is exposed to make a video printout of the subject. In carrying out the shading correction method, the shading correction device employs a memory for storing the shading correction data, a frame memory for storing image data of a subject to be printed and a device for adding the shading correction data read out from the memory and the image [[date]] data readout from the memory.

United States Patent~~s 4,979,598 and~~ 4,979,042 purports to disclose apparatus for correcting shading effects in video images for a document retrieval system. The document retrieval system captures an image of a document in electronic form using linear CCD imagers or a CCD array. The apparatus reduces the size of the memory required to store, correction information by defining the two dimensional non-uniformity characteristics in terms of two functions that are orthogonal. The orthogonal correction functions are stored in separate memories. During a scan, a pixel counter addresses the X memory while a line counter addresses a Y memory. The correction factors thus obtained are applied sequentially to correct the pixel data value at the current X and Y coordinates. The sources of non-uniformity which are corrected by the apparatus include use of the lens having non-uniformities which are generally known in the optical art as the "cos" law

(sometimes known as the cosine law) to focus the image onto the capturing device and, the CCD pixel sensitivity variations and spot uniformities that may occur in an illumination source such as a lamp filament.

~~The above described prior art represent the typical electronic correction devices and methods to correct shading in an optical image for a variety of video imaging apparatus and system.~~

The above-identified references indicate approaches directed to correction of shading associated with inherent deficiencies in either/both the imaging performance of video cameras/sensors and such cameras' optics. As previously described, other known approaches are directed to optimizing light sources and guides. Notwithstanding these approaches, alone or together, differential picture brightness remains a problem in acquired images of interior spaces due to illumination deficiencies.

Differential picture brightness due to illumination deficiencies remains a particularly significant problem in the medical field wherein a patient's health typically is at stake. As an example, the success or failure of laparoscopic surgery may depend in substantial part on the quality at which the operative site is imaged for the surgery team.

Accordingly, there is a need for medical imaging instruments, apparatus and methods that address illumination deficiencies, particularly uneven illumination of the operative site/inspection area.

SUMMARY OF THE INVENTION

A novel, new and unique compensating apparatus or video signal compensator for compensating differential picture brightness of an optical image due to uneven illumination is disclosed and taught by this invention. The compensating apparatus or video signal compensator

includes a device for generating a compensating signal substantially representing at least one parameter of a compensating waveform required for the differential picture brightness of an optical image to produce a [[video]] signal representing an optical image having a substantially uniform brightness. An adder is operatively coupled to the compensating video signal generating device and a video signal for adding the compensating signal and the video signal to produce a ~~compensating signal used as~~ compensated video signal, or for using the compensating signal to an input to a video signal processor adjusting its gain both vertically and horizontally by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference. The compensated video signal represents an image having a substantially uniform brightness.

In addition, a new novel and unique method for compensating for differential picture brightness of an optical image due to uneven illumination is discloses and taught by this invention. The method comprises the steps of: (a) generating with a compensating signal device a compensating signal substantially representing at least one parameter of a compensating waveform required for the differential picture brightness of an optical image to produce a video signal representing an optical image having a substantially uniform brightness; and (b) adding with an adder operatively coupled to the compensating signal generating device and a video signal the compensating signal and the video signal to produce a compensating video signal used as an input to a video signal processor adjusting its gain both vertically and horizontally compensated by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference compensating the video signal to represent an optical image having a substantially uniform brightness.

In the preferred embodiment of the apparatus and method of the present invention, the differential picture brightness of an optical image is brighter at its center than at its periphery or

edges. Thus, the compensating video signal is used to adjust the gain of the video signal processor both vertically and horizontally by increasing the gain of the video signal in

response to a sawtooth waveform representing the periphery or edges of the optical image and reducing the gain of the video signal in response to the parabolic waveform representing the center of the optical image compensating the video signal to represent an optical image having a substantially flat brightness.

In the Sony Vidicon Shading Circuit, the sawtooth wave generator and parabolic wave generator were used to generate a compensating signal to correct for thè deficiencies introduced into or added into the video signal by the vidicon tube itself. The Sony Vidicon Shading Circuit was not used to correct for differential picture brightness of an optical image due to uneven illumination from an optical instrument imaged onto a vidicon tube or sensor.

The correction circuit of United States Patent 5,343,302 generated a parabolic wave signal and the level thereof was adjusted in accordance with the zoom and iris settings of the camera's optical system. Further, the parabolic wave signal of the correction circuit of united states Patent 5,343,302 was clipped to perform shading corrections principally in the case of the reduction of the light intensity ratio from the periphery to the center of the image caused by aperture eclipse and in the case of f-drop (i.e. reduction of the f-number) at the telephoto lens setting. The correction circuit of United States Patent 5,343,302 was not used to correct for, nor does the correction

circuit therein disclose, suggest or teach compensating for differential picture brightness of an optical image from an optical instrument imaged onto video camera or sensor.

The method and apparatus of United States Patent 5,157,497 detects and compensates for white shading errors in a digitized video signal using, a flat white calibration target. The method and apparatus of United States Patent 5,157,497 was based on use of a flat white calibration target and was not used to correct for differential picture brightness of an optical image from an optical instrument imaged onto video camera or sensor.

The shading correction device disclosed in United States Patent 5,053,879 is used for a

video printer and employs a memory for storing the shading correction data, a frame memory for storing image date of a subject to be printed and a device for adding the shading correction data read out from the memory and the image data readout from the memory. The shading correction device of United States Patent.5,053,879 is based on adding shading correction data read out from the memory with the image data readout from the memory. United States Patent 5,053,879 does not disclose, teach or suggest correcting for differential picture brightness of an optical image having uneven illumination from an optical instrument imaged onto video camera or sensor.

The apparatus and method disclosed in United States Patents 4,979,598 and 4,979,042 disclose and teach correction of shading effects in video images for a document retrieval system. The document retrieval system capture an image of a document in electronic form using linear CCD imagers or a CCD array. The apparatus defines the two dimensional non-uniformity characteristics in terms of two functions that are orthogonal about orthogonal axes. The sources of non-uniformity which are corrected by the apparatus compensate for lens deficiencies, the CCD pixel sensitivity variations and spot non-uniformities that may occur in an illumination source such as a lamp filament. The apparatus and method disclosed in United States Patents 4,979,598 and 4,979,042 do not teach, disclose or suggest compensating differential picture brightness of an optical image due to uneven illumination from an endoscope imaged onto a video camera.

The prior art does not disclose, teach or suggest compensating video images for the non-uniform characteristics of a light source located at or transmitted by a light guide to the distal end of an optical instrument to illuminate an operative site or inspection area.

The apparatus and method of the present invention overcomes several of the problems of the prior art including compensating for differential picture brightness due primarily to the non-uniform characteristics of a light source ~~located as~~ or a light source operatively coupled to a light guide for illumination of an operative site or inspection area. The light energy is typically reflected from the surface of the operative site or inspection area. The reflected light energy and optical image developed therefrom in an optical instrument include the non-uniformities or unevenness of

the light energy.

One advantage of the present invention is that the compensation correction apparatus and method can be used for ~~optical~~ medical images developed form a variety of optical instruments including endoscopes having an optical ~~imager~~ image imaged onto a video sensor or video camera.

Another advantage of the present invention is that the amount and shape required for compensation correction can be adjusted as required or an approximation thereof can be provided with adjustable wave shaping devices or circuits.

Another advantage of the present invention is that optical instruments developing an optical image having differential picture illumination with an uneven light return path and light and dark areas which are imaged onto a video sensor or video camera can have the so produced optical images compensated electronically such that the brightness of the areas is more uniform or flat.

Another advantage of the present invention is that a sampling circuit or sensing circuit may be used to determine the correction required for appropriate compensation or an approximation thereof and such circuits can be used with adjustable wave shaping devices or circuits.

Another advantage of the present invention is that a the light returned from the cosine angle of the reflecting surface can be sampled or sensed and a correction based thereon can be developed and applied to video amplifiers to reduce the gain in the bright areas and increase the gain in the dark areas to produce a video signal representing an optical image having substantially even field illumination.

Another advantage of the present invention is that the compensating signal required for making the corrections and the means for applying the compensating signal may be analog, digital or other means, e.g., a hybrid of analog and digital.

Another advantage of the present invention is that a video signal compensator can produce corrections wherein the differential picture brightness of an optical image is brighter at its center than at its periphery or edges. The video signal compensator includes an adder which adds a

sawtooth waveform, a parabolic waveform and a video signal to produce a compensating signal used as an input to video signal processor adjusting a its gain both vertically and horizontally by increasing the gain of the video signal in response the sawtooth waveform representing the periphery of the optical image and reducing the gain of the video signal in response to the parabolic waveform representing the center of the optical image compensating the video signal to represent an optical image having a substantially flat brightness.

Another advantage of the present invention is that a video signal compensator can produce corrections wherein the differential picture brightness of an optical image is brighter at its periphery or edges than at its center. The video signal compensator includes an adder which adds a sawtooth waveform, a parabolic waveform and a video signal to produce a video compensating signal used as an input to a video signal processor adjusting its gain both vertically and horizontally by decreasing the gain of the video signal in response the sawtooth waveform representing the periphery of the optical image and increasing the gain of the video signal in response to the parabolic waveform representing the center of the optical image compensating the video signal to represent an optical image having a substantially flat brightness.

Another advantage of the present invention is that a video signal compensator can include a control device operatively coupled to an adder to increase the brightness of the output video signal to a level which is greater than the average of the differential brightness of the optical image due to the uneven illumination.

Another advantage of the present invention is that a video signal compensator can be used for compensating differential picture brightness of an optical image due to uneven illumination from an endoscope imaged onto a video sensor or video camera.

Another advantage of the present invention is that a method for compensating for differential picture brightness of an optical image due to uneven illumination using a video signal compensator is shown.

Another advantage of the present invention is that a method for compensating for an

uneven light path in an endoscope or other optical instrument is shown. The method for compensating can be used to compensate for non-uniformities of the optical system alone or in combination with an illumination system having non-uniformities as used in television viewing systems.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages of this invention will be apparent from the following description of the preferred embodiment of the invention when considered with the illustrations and accompanying drawings which include the following Figures:

Fig. 1 is a front, top and left end perspective view of a endoscope in the form of a laparoscope having a video camera operatively coupled to an eyepiece located at the proximal end thereof for practicing this invention;

Fig. 2 is a partial top plan sectional view showing the proximal end of another embodiment of a laparoscope having a video sensor directly operatively attached thereto for practicing this invention;

Fig. 3 is a distal section perspective view of on embodiment of a laparoscope of Fig. 1 showing the distal tip having a transparent member for passing an optical image, the location of the fiber optic light guide around the periphery of the laparoscope and two nozzles for directing fluid across the exterior surface of the transparent member;

Fig. 4 is a distal end elevational view showing another embodiment of a laparoscope having a single nozzle for directing fluid across the exterior surface of the transparent member and the location of the fiber optic light guide around the periphery of the laparoscope and nozzle;

Fig. 5 is a distal end elevational view of yet another embodiment of Fig. 4 showing an additional working channel and orientation of the fiber optic light guide;

Fig. 6-is a distal end elevational view of yet another embodiment of Fig. 5 having a fourth channel and orientation of the fiber optic light guide;

Fig. 7 is a distal end elevational view of yet another embodiment of a laparoscope having a nozzle, an irrigation flow orifice, which could be utilized as a first working channel, and an accessory or working channel which is larger that the first channel and which is adapted to pass working accessories and orientation of [[the]] a fiber optic light guide;

Fig. 8 is block diagram of an analog video camera having a video signal compensator located between a preamplifier and video signal processor;

Fig. 9 is a block diagram of a digital video camera having a preamplifier, digital-to-analog converter, digital signal ~~processing~~ processing, and an analog-to-digital converter ~~with the~~ including a video signal processor located after the analog-to-digital converter;

Fig. 10 is a block diagram of another embodiment of a digital video camera having a preamplifier, video signal compensator, digital-to-analog converter, digital signal processor, analog-to-digital converter and an output device, and ~~a monitor~~ an output device, and illustrating that the video signal processor is located before the analog-to-digital converter;

Fig. 11 is a block diagram of another embodiment of a analog video camera having a video sensor, preamplifier, analog video signal processor, video signal compensator and ~~a monitor~~ an output device, and illustrating that the video signal ~~processor~~ compensator is located after the analog video signal processor;

~~Fig. 12(a) and Fig. 12(b) represent graphs showing: (i) the brightness of the optical image represented by a video signal having a differential picture brightness where the center is brighter than a reference level and the periphery is less bright than a reference level; and (ii) the brightness of the optical image represented by a video signal after adjustment by the video signal processor in response to a compensating signal which has been added to the video signal compensating the video signal to represent the optical image having a substantially uniform brightness, respectively;~~

Figs. 12(a) and 12(b) show, respectively: (i) a video signal representing an optical image having differential picture brightness and (ii) a compensated video signal representing an optical image having substantially uniform brightness.

[[Fig.]] Figs. 13(a) and 13(b) are pictorial representations of respectively: (i) an optical image wherein the center is brighter than a reference level and the periphery is less bright than a reference level and [[of]] (ii) an optical image wherein the center is less bright than a reference level[[;]] and [[(ii)]] the periphery is brighter than a reference level~~, respectively~~;

Fig. 14 is a pictorial representation of a compensated video signal of an optical image having a substantially uniform brightness;

Figs. 15(a), 15(b) and 15(c) ~~are waveforms~~ show, respectively, a waveform of a sawtooth wave generator having an increasing slope, a waveform of a sawtooth wave generator having an decreasing slope and a waveform of a parabolic wave generator having controlled amplitude and orientation~~, respectively~~;

Fig. 16 is a schematic diagram of the preferred embodiment of a video signal compensator of the present invention adapted to be located in a video camera at a location illustrated in Fig. 8;

Fig. 17 is a block diagram of a digital video camera having a digital storage device for storing a digital representation of the video signal having [[the]] differential brightness due to uneven illumination ~~cross-sectional and a digital signal processor for generating a digital compensating signal which is converted by a digital-to-analog converter to an analog signal before being applied to an adder to produce a compensated analog video output • signal from the digital signal processor~~; and

Fig. 18 is a block diagram of a digital video camera having a digital storage device for storing a digital representation of the video signal ~~having the differential brightness due to uneven illumination cross-sectional and a programmable digital processor having~~ and an 8 x 8 pixel multiplexer/processor for producing a compensated analog video output signal;

Fig. 19 is a waveform of a video signal from a small diameter endoscope illustrating the

noise before and after the video signal representing the picture information;

Fig. 20 is a waveform of [[the]] a video signal from a small diameter endoscope illustrating the action of a sensing device for sensing and removing the noise before and after the video signal representing the picture information; and

Fig. 21 is a block diagram of a sensing device for sensing and removing the noise [[which]] of Fig. 19 which sensing device, in the preferred embodiment, is in the form of a blanking circuit.

Fig. 22 is a high level block diagram of a medical imaging instrument or system, in accordance with the invention.

~~DESCRIPTION OF THE PREFERRED EMBODIMENT~~ DETAILED DESCRIPTION

Before commencing with the detailed description of the preferred and other embodiments of the present invention, the following review will provide a better understanding of the application and utility of the present invention to optical instruments or optical devices which are used to produce an optical image directed onto or imaged onto a video sensor or camera. As an example, the following review will provide background to advance understanding of the application and utility of the present invention in medical imaging instruments, apparatus and methods. The background is directed particularly to video applications, wherein the invention is directed to enhance real-time motion signals (e.g., frame by frame).

Video cameras used with optical instruments for medical and industrial applications generally are known as an "analog video camera", a "digital video camera" or a "digitally controlled video camera".

In an analog video camera, the video sensor is typically separated from a video signal processor which is sometimes referred to as the video camera. The output of a [[CCD]] video sensor (e.g., a CCD) is an analog signal which is applied to a preamplifier. The output of the preamplifier is operatively connected to a remotely disposed video signal processor either directly

by electrical conductors or indirectly by a wireless device such as an infrared transmitter and receiver. The output of the video signal processor is an analog video signal in a preselected format, e.g., NTSC, Y/C, RGB or other ~~Format~~ format. All signal transmission and processing is accomplished using analog techniques.

In a digital video camera, the video sensor is again typically separated from the video signal processor. The output of a CCD is an analog signal which is applied to a preamplifier. The output of the preamplifier is operatively connected by an analog-to-digital converter to a remotely disposed digital signal processor. The output of the digital signal processor is applied to a digital-to-analog converter wherein the output thereof is [[a]] an analog video signal in a preselected format, e.g., NTSC, Y/C, RGB or other ~~Format~~ format.

It is also envisioned that the preselected format, encoding scheme or standard television system encoding format could be the PAL format, SECAM format or any other format utilized in a country as a standard of that country. In addition, the format could be a proprietary format for use in a closed circuit television system. The use of either the term "NTSC, Y/C, RGB or other ~~Format~~ format," or the term "format" alone in appropriate context" is intended to all cover of such preselected formats of output video signals.

In a digitally controlled video camera, the video sensor, preamplifier and remotely disposed video signal processor are substantially operationally the same as the analog videocamera. However, a digital system controls the operation of each of the components and controls transfer of signals between components, all under control of a digitally programmed devices, However, the output of the video camera is an analog video signal in a preselected format, e.g., NTSC, Y/C, RGB or other ~~Format~~ format.

~~In a digitally controlled video camera, the video sensor preamplifier and remotely disposed video signal processor are substantially operationally the same as the analog video camera.~~ Each of the above-described video cameras, as well as other video cameras, are expressly contemplated within the scope of the invention. Moreover, the video sensors of such cameras may

be variously implemented without departing from the principles of the invention. The term "video sensor" as used herein is intended to collectively and broadly refer to [[a]] any video sensor, ~~line sensor, solid state sensors, area sensors, CAD, vidicon tubes, CCD sensors or other video sensors used in practicing this invention~~ including solid state sensors and tube-based sensors, including, as non-exhaustive examples, line sensors, area sensors, CCDs, CMOS sensors and other photodiode/photoconductor arrays, as well as vidicon and orthicon tubes and combinations of same. The term "video sensor" includes sensors located at the proximal end of the optical instrument, such as an endoscope. Also, the term "video sensor" is intended to cover all such sensors located at a different location in the optical instrument, such as ~~at a CCD~~ (a) sensor located at the distal tip of an endoscope, or ~~to a video~~ (b) a sensor video camera, the camera being operatively attached to ~~an optical instrument, endoscope~~ a medical instrument (e.g., an endoscope) or other optical device wherein an optical image developed by the ~~optical~~ medical instrument or optical device, having an illumination provided from a light source or a light guide, is imaged onto ~~a CCD sensor or video camera~~ the video sensor.

Referring now to Fig. 1, Fig. 1 illustrates the preferred application for using the teachings of the present invention in an endoscope. Fig. 1 illustrates an instrument, generally as 30, which is an endoscope in the form of a laparoscope for medical surgery. The instrument 30 includes ~~a rigid elongated sheath tube 32" with~~ a housing 32 (e.g., a rigid sheath tube) having a selected length and a distal section or end 36 and a proximal section or end 38. The distal end 36 terminates in a distal tip shown generally as 44. The interior of the laparoscope includes an optical image transferring [[means]] structure. The optical image transferring means structure may be variously implemented, including as a system or member, ~~typically~~ but typically comprises a lens system including relay lenses. In any case, the optical image transferring structure provides for transferring an optical image from the distal tip 44 (through the ~~ridged elongated sheath tube 32~~ housing 32) to the proximal end 38 of the laparoscope. Although the elongate housing 32 is generally referred to herein as being rigid, it is understood that the housing and, in turn, the instrument 30 may be other

than rigid (e.g., flexible or semi-flexible), without departing from the principles of the invention.

The proximal end 38 of the laparoscope is operatively connected to an extension member shown generally as 48. The extension member 48 includes ~~means for supporting~~ structure to support a light post 52 and ~~means for defining~~ structure to define openings or ports for two channels, which openings are shown as 54 and 60 (60 being visible in Fig. 2). ~~Valve means~~ Valves, which in the preferred embodiment are trumpet valves 58 and 62, are operatively connected to openings 54 and 60 respectively. An eyepiece housing, shown generally as 64, terminates in an eyepiece 66 which permits a surgeon to view the optical image transferred through the laparoscope. However, in Fig. 1, a video sensor, typically a CCD sensor and preamplifier, shown generally as 68, is operatively connected to the eyepiece to convert the optical image into a video signal. The video signal is ultimately processed by a video signal ~~processing means, for example 134 in Fig. (8),~~ processor (such as processor 134 of Fig. 8) to produce a video image on a monitor or video signals for storage of the video image on magnetic tape or other storage [[means]] device, or for printing the image, or for other purposes.

The laparoscope 30 may include a plurality of channels which can be used for a number of functions. Several species or embodiments of laparoscopes are disclosed herein in Figs. 1 through 7 to show that the present invention can be used with a wide variety of endoscopes or optical instruments.

Fig. 2 shows the proximal end of another embodiment of a laparoscope 30 having a video sensor housing, shown generally as 64', which is adapted to have a video sensor 68' directly operatively attached thereto for practicing this invention. In addition, Fig. 2 illustrates pictorially that a light source 67 is operatively coupled to the light post 52. The light post 52 is operatively connected to a fiber optic light guide ~~shown as~~ 72 in Fig. 4. The fiber "optic light guide transmits the light energy from the light post 52 located at the proximal end 38 of the laparoscope 30, ~~through the rigid elongated sheath tube 32~~ housing 32 to the distal section or end 36. The light energy is then is directed onto the operative site or inspection area to illuminate the same. (Hereinafter, the

operative site and inspection area are sometimes referred to, alone or together, as the "target site".)

Typically the light sources are metal halide, xenon light sources or other similar devices. The light energy from the light source 67 is in the form of a light beam or radiation beam that has defined spatial distribution characteristics which generally includes that center thereof has higher brightness than the periphery or edges thereof. The light energy is applied to the fiber optic light guide, or light guide in other optical instruments, through a light post or equivalent device such as a coupling lens or cone system. The light energy typically is white, visible light; however, it is to be recognized that the light energy may include frequency components outside the visible light spectrum, either supplemental to or in substitution for some or all of the white light frequencies. Examples include infrared and x-ray radiation.

The fiber optic light guide, as well as the other light guides, transmits the light energy and retains the defined spatial distribution characteristics of the light energy. The light energy is directed onto the operative site or inspection area to illuminate the same. The reflected light returned from the cosine angle of the reflecting surface is transmitted by the optical image transferring system to the proximal end of the optical instrument 30 where the optical image having the differential picture brightness developed by the spatial distribution characteristics of the light energy, is imaged on the video sensor 68'. In the alternative, the optical image can be sampled or sensed, using digital sampling and measuring techniques which are well known in the arc, and a correction or compensating signal based thereon can be developed and applied to video amplifiers to reduce the gain in the bright areas and/or increase the gain in the dark areas to produce a video signal representing an optical image having substantially even field illumination.

In Fig. 2, the fiber optic light guide used for illumination of the operative site or inspection area can be varied in structure as illustrated in the embodiments of Figs[[,]]. 4 through 7 as described herein below. However, the non-uniform characteristics of a light source 67 [[is]] are transmitted through the light guide in the optical instrument to the distal end ~~and illuminates~~ to

illuminate the operative site or inspection area which produces the optical image having a differential picture brightness due to uneven illumination.

Fig. 3 shows another embodiment of a distal end of a laparoscope utilizing the teachings of the present invention. In the embodiment of Fig. 3, the distal tip 44 includes [[means]] structure which are located within the ~~rigid elongated sheath tube 32~~ housing 32 for defining at the distal end 36 a [[means]] mechanism for directing a fluid flow across the exterior surface of an image passing [[means]] device ~~shown generally as~~ 76. Image passing [[means]] device 76 including the distal end of the optical image transferring system [[of]] or member is located in the center of an aperture 74. In Fig. 3, the image passing [[means]] device [[may be]] comprises one or more of a distal lens, a window or transparent surface ~~for a CCD~~ for or of a CCD sensor~~, or video sensor~~ (or other video sensor), fiber optics, or the like. In Fig. 3, the [[means]] mechanism for directing fluid flow across the exterior surface ~~is shown generally as~~ comprises a nozzle 80. The nozzle 80 is located in the space ~~shown as~~ 70~~ which houses a fiber optic light guide means which is shown in great detail in Figs, 4 through 7~~. In Figure 3, the mechanism that directs fluid flow across the exterior surface of the image passing device also comprises a second nozzle 82, such nozzle being located in the space 70 at a selected distance from nozzle 80. Such mechanism may comprise any selected number of nozzles 80, 82 and/or other selected structure.

Fig. 4 shows yet another embodiment of a laparoscope having a nozzle 80 and irrigation channel 86. Specifically, the distal end 44 of the laparoscope includes ~~a transparent member~~ an image passing device 76 which is located in the aperture opening 74. In Fig. 4, the nozzle 80 which is located in space 70[[,]] directs a fluid flow across the exterior surface of the ~~transparent member~~ image passing device 76 and ~~second~~ irrigation channel 86 functions as an irrigation orifice. Of course, such a nozzle is not required to practice this invention, but keeping the ~~transparent member~~ image passing device clear of image impeding material substantially improves the quality of the optical image passed by the endoscope.

The fiber optic light guide 72 typically comprises one or more light fibers, bundled or

<ins>otherwise.</ins> The light fibers forming the fiber optic light guide 72 are <ins>arranged in plural bundles, the bundles being disposed in space 70. Typically, as shown, the bundles of light fibers are</ins> located around the optical image transferring system or member and are positioned around the various orifices and nozzles as depicted in Fig. 4.

Fig. 5 illustrates the structure of a distal end of a laparoscope similar to [[the]] <ins>that</ins> illustrated in Fig. 4 with the addition of a third channel 90 which can be used for other [[uses]] <ins>purposes</ins> during surgery, such as for example as an aspiration orifice.

Fig. 6 illustrates the structure of yet another distal end of a laparoscope similar to [[the]] <ins>that</ins> illustrated in Fig. 5 with the addition of a fourth channel 92. Channels 86, 90 and 92 are equally [[space]] <ins>spaced</ins> around the optical image transferring system or ~~optical image transferring~~ member. As in Fig. 4, the light fibers forming the fiber optic light guide 72 are located around the optical image transferring system or member and are positioned around the various orifices and nozzles.

Fig. 7 illustrates yet another embodiment of a laparoscope wherein the distal end 44 has a different structure than the structures of Fig. 3 through 6. One difference is that the ~~transparent member~~ <ins>image passing device</ins> 76 is [[of]] <ins>off</ins> center relative to the elongated sheath tube 32. As such, the aperture opening 74 is off center relative to the elongated axes 102, but is coaxial with the central axis 100 of the ~~transparent member~~ <ins>image passing device</ins> 76. As a result of the offset of the [[axis]] <ins>axes</ins>100 end 102, an expanded space shown generally as 110 is provided between the ~~rigid elongated sheath tube~~ <ins>housing</ins> 32 and the optical image transferring member located within the laparoscope. A working channel 96 is provided in the expanded space 110. The light fibers forming the fiber optic light guide 72 are located around the optical image transferring member and are positioned around the various orifices, nozzles and working channels.

In each of the structures of the distal ends of endoscopes illustrated by Figs. 2 through 7, the fiber optic light guide 72 directs the light energy out of the distal end and, in each embodiment, the light energy retains the ~~non-uniform~~ <ins>non-uniformity</ins> of or unevenness in illumination of the light

source, e.g., light source 67 as shown in Fig. 2. Of importance, ~~the compensating~~ as is described further hereinafter, a ~~apparatus or~~ video signal compensator are operative with any of the optical images developed by the endoscopes illustrated in Figs. 1 through 7 so as to produce a video signal representing an optical image having substantially uniform brightness, ~~due to~~ notwithstanding the light guide's directing of non-uniform or uneven illumination.

In the alternative, the fiber optic light guide 72 could be eliminated and electrical conductors could be extended through the endoscope to [[the]] a light bulb or other light source located at the distal end. ~~The light bulb or~~ As an example, the light bulb or other light source could be located in the position shown by working channel 96 in Fig. 7. (The light bulb, light source, light guide and other structure associated with illuminating a target site are sometimes referred to herein, individually, collectively and grouped, as an "illuminator'.)

Fig. 8 illustrates a preferred embodiment of ~~a compensating apparatus~~ an analog video camera for practicing this invention. An optical image having differential picture brightness due to uneven or non-uniform illumination (the term "uneven illumination" being [[use]] used to describe this characteristic) ~~developed from an optical instrument having a light guide operatively coupled to a light source~~ is illustrated by arrow 118. The optical image having differential picture brightness due to uneven illumination 118 is imaged directly or indirectly onto a video sensor 120. The output from the video sensor is an analog video signal which is applied to a preamplifier 122.

The video sensor 120 and preamplifier 122 are generally located with or operatively attached to the optical instrument as described in connection with Figs. 1 and 2. In such event, electrical conductors [[124]] 126, which are operatively connected to the preamplifier 122, extend from the proximal end of a laparoscope to a remotely disposed video signal processing apparatus depicted by dashed box 128. The video signal processing apparatus 128 includes a video signal compensator ~~or compensating apparatus~~ 130 (the video signal compensator is sometimes referred to herein as a "compensating apparatus").

The video signal compensator ~~or compensating apparatus~~ 130 performs the function of generating a compensating signal which is used to compensate the video signal representing the optical image having differential picture brightness due to uneven illumination 118. The ~~compensating~~ output signal of the video signal compensator ~~or compensating apparatus~~ 130, [[shown]] as provided on output 132, is applied as an input to a standard analog video signal processor 134 which processes video signals to produce an analog [[video]] signal in a preselected format, e.g., NTSC, Y/C , RGB or other ~~Format~~ format.

~~When the compensating signal on output 132 is added to the input of the video signal processor 134, the~~ The output from the video signal processor 134, appearing on output 136, is a formatted video signal compensated to represent the optical image having substantially uniform brightness. The compensated video ~~output~~ signal on output 136 is applied to ~~a monitor, video storage device, printer or other video~~ an output device depicted by box 138. (Hereinafter, the term "output device" contemplates, without limitation, display devices (e.g., flat panel display technology, light valve technology, tube technology or otherwise), printing devices, storage devices (e.g., CD, DVD or other optical or magneto-optical storage, VCR, RAID, hard drive, or other analog/digital, temporary/semi-permanent/permanent storage), networking devices and other similar devices.)

As shown in Figure 8, the video signal compensator 130 is located between the preamplifier 122 and the video signal processor 134. The advantages of locating the video signal compensator 130 in this position is that the video signal is in analog format as it is generated by the [[CCD]] video sensor. The preamplifier generally performs the function of providing sufficient amplification of the analog video signal to drive the electrical conductors with the analog video signal so as to deliver an amplified video signal to the remote video signal ~~processor~~ processing apparatus 128. Another advantage is that the ~~preamplifier~~ amplified video signal and the compensating signal can be added multiplied, mixed, interpolated, extrapolated or otherwise applied together before or at the front end to the video signal processor such that the video signal processor ~~process a~~ outputs a formatted, compensated video signal.

As is readily apparent to anyone of skill in the art, the compensating signal may be variously applied to the video signal. As an example, the compensating signal may be applied within the video signal processor 134. To do so, the video signal processor 134 has applied, as inputs, the compensating signal and the amplified video signal, each via output 132. The so-input amplified video signal, in such case, is passed through the video signal compensator 130. In such case, the video signal processor 134 may apply the compensating signal so as to control the processing (e.g., the gain) of the video signal, or it may add, multiply, mix, interpolate, extrapolate or otherwise process the compensating signal with the video signal. As another example, the video signal compensator 130 generates the compensating signal and applies that compensating signal with the video signal, so as to output to the video signal processor 134 a compensated video signal for formatting. The application is implemented by adding, multiplying, mixing, interpolating, extrapolating or otherwise applying together the compensating signal and the video signal.

The compensator 130 may be variously implemented in generating the compensating signal. As an example, the compensator 130 can be implemented to generate the compensating signal from components of the video signal. These components typically include one or more, or combinations of: timing components, synchronization components, and test, marker or other references embedded in the video signal (e.g., in the content portion thereof). Use of embedded references engenders advantages, including enabling the system to recognize and track changes in the orientation of the endoscope. Such changes, which typically arise from manipulations related to the applicable medical procedures and which include rotation about the endoscope's elongate axis, tend to result in variations in illumination, including changes in differential picture brightness. If the differential picture brightness characteristics are the same, but merely rotated or otherwise re-oriented, the tracking enable the compensation to be adapted thereto.

However, it is also possible to add multiply, mix, interpolate, extrapolate, or otherwise apply together the amplified video signal and the compensating signal ~~to the video signal~~ after processing of the video signal to a preselected format. For example, Fig. 9 illustrates a typical

digital video camera. In Fig. 9, the optical image having differential picture brightness due to uneven illumination 118 is imaged directly or indirectly onto a video sensor 120. The output from the video sensor is an analog video signal which is applied to a preamplifier 122 as described above relative to Fig. 8.

The amplified video signal appearing on ~~output~~ conductors 126 is applied to an analog-to-digital converter 142, the output of which is a digitized video signal representing the optical image having differential picture brightness due to uneven illumination. The output of the analog-to-digital converter 142 is applied to a digital signal processor 146 where the output signal is a processed ~~analog~~ digital video signal representing the optical image having differential picture brightness due to uneven illumination. The output of the digital signal processor 146 is applied to a digital-to-analog converter 150, the output of which is an analog signal in a standard or preselected format, such as an NTSC, Y/C, RGB or other ~~Format~~ format video signal. A video signal compensator 154, utilizing the teachings of this invention, ~~then~~ produces a compensating signal in the preselected format which is ~~added to and compensates the video signal to represents~~ added, multiplied, mixed, interpolated, extrapolated or otherwise applied with the video signal output by the digital-to-analog converter 150, so as to produce a formatted, compensated video signal representing an optical image having substantially uniform ~~illumination~~ brightness. As an example, the video signal compensator 154 generates the compensating signal and applies that compensating signal with the video signal. The application is implemented by adding, multiplying, mixing, interpolating, extrapolating or otherwise processing together the compensating signal and the video signal. The compensated ~~output~~ video signal appearing on output 156 is applied to a monitor, video storage device, printer or other [[video]] output device depicted by box 158.

The compensating ~~waveform~~ signal may also be ~~added to the analog or digital signal processor~~ otherwise introduced. Figs. 10 and 11 discussed below are exemplary.

In Fig. 10, the compensating signal is ~~added to the video signal~~ produced before digital processing of the video signal. For example, Fig. 10 illustrates a digital video camera wherein the

optical image having differential picture brightness due to uneven illumination 118 is imaged directly or indirectly onto a video sensor 120. The output from the video sensor is an analog video signal which is applied to a preamplifier 122 as described above relative to Fig. 8.

The amplified video signal from the preamplifier 122 is applied to ~~an analog-to-digital converter~~ video signal compensator 160, the output of which is ~~a compensated analog~~ an analog compensated video signal representing the optical image having ~~differential picture brightness due to uneven illumination~~ substantially uniform brightness. The output of the video signal compensator 160 is applied to an analog-to-digital converter 161 wherein the ~~digital signal is~~ output is a digital signal that is applied to a digital signal processor 162. The output of the digital signal processor 162 is a digitized, formatted compensated video signal which is applied to a digital-to-analog converter ~~163 wherein the output signal from~~ 163. The output of the digital-to-analog converter 163 is a ~~processed~~ formatted analog video signal representing the optical image having ~~differential picture brightness due to uneven illumination~~ substantially uniform brightness. The output of the digital-to-analog converter 163 is applied to a monitor, video storage device, printer or other [[video]] output device depicted by box 164.

As described, the digital signal processor 162 has applied, as an input, the compensated video signal output from the video signal compensator 160. To do so, the compensator 160 adds, multiplies, mixes, interpolates, extrapolates or otherwise applies the compensating signal with the amplified video signal. In the alternative, the compensator 160 generates the compensating signal and passes through the amplified video signal, both as inputs to the analog-to-digital converter 161. In the latter case, either the analog-to-digital converter 161 or the digital signal processor 162 applies the respective signals to produce the compensated video signal.

Fig. 11 illustrates another embodiment of a typical analog video camera having a video signal compensator located after the analog video signal processor. In Fig. 11, the optical image 118 having differential picture brightness due to uneven illumination 118 is imaged directly or

indirectly onto a video sensor 120. The output from the video sensor 120 is an analog video signal which is applied to a preamplifier 122 as described above relative to Fig. 8.

The amplified video signal from the preamplifier 122 is applied to an analog video signal processor 165. The output from the analog video signal processor 165 is applied to a video signal compensator 166 ~~where the output signal is a processed analog video signal representing the optical image having differential picture brightness due to uneven illumination~~ so as to output a formatted, compensated video signal representing the optical image having substantially uniform brightness. The output of the video signal compensator 166 is in a standard or preselected format, such as an NTSC, Y/C, RGB or other ~~Format~~ format video signal. The video signal compensator 166, utilizing the teachings of this invention, produces a compensating signal ~~in the preselected format~~ (e.g., in or responsive to the preselected format) which is ~~added to and compensates the video signal to represent an optical image having substantially uniform illumination~~ added, multiplied, mixed, interpolated, extrapolated or otherwise applied with the formatted video signal, so as to produce the formatted, compensated video signal. The compensated output signal from the video signal compensator 166 is applied to a monitor, video storage device, printer or other [[video]] output device depicted by box 168.

It is envisioned that the video signal compensator could be [[used]] implemented at numerous locations in the video signal circuit path, or ~~even in the digital signal processor~~ integral with the video signal processor (whether analog or digital).

Figure 12(a) is a graph of [[the]] a video signal depicted by waveform [[162]] 171 representing [[the]] a optical image having differential picture brightness due to uneven illumination. [[The]] A reference line ~~for brightness is shown as~~170 is depicted which represents an optical image having substantially uniform brightness. The portion shown as [[172]] 171 of the waveform 170 represents that part of the optical image 118 which is less bright than ~~a reference 170~~ the optical image represented by the reference line 170, and the portion shown as 174 shows that part of the optical image 118 which, at its peak, is brighter than the optical image represented by the

reference line 170.

Figure 12(b) is a graph of the compensated video signal depicted by waveform 178 representing the optical image ~~after the gain of the video signal has been compensated by the compensating signal generated by the video signal compensator 130 of Fig. 8. The reference line for brightness is shown as 170. The portion shown as 180 of the wave form 178 represents that part of the optical image 118 which was less bright than a reference 170 output video signal and its gain both vertically and horizontally was compensated by increasing the gain of the video signal representing that part of the optical image which was less bright than the reference 170.~~

~~With respect to the portion of the compensated video signal shown as 182 which was brighter than the reference 170, its gain was compensated both horizontally and vertically by reducing the gain of the video signal compensating the video signal to represent an image having a substantially uniform brightness.~~ of Fig. 12(a) having substantially uniform brightness. The compensated video signal of waveform 178 is generated by conditioning the waveform 171. In this illustration, the waveform 178 is generated by conditioning the waveform 171 with one or more compensating signals so that (a) the amplitudes of the portion 174 of waveform 171 which are brighter than desired are appropriately decreased to form portion 180 of waveform 178, (b) the amplitudes of the portions 172 of waveform 171 which are less bright than desired are appropriately increased to form portions 180 of waveform 178 and (c) the amplitudes of the portions 172 of waveform 171 which correspond to sites which are expected to be non-illuminated or non-imaged are appropriately decreased to form portions 181 of waveform 178. As such, the waveform 178 corresponds substantially closely at relevant times to the level of the reference line 170, such correspondence reflecting an optical image having substantially uniform illumination.

It is to be recognized that, while Figs. 12(a) and (b) respectively depict a small portion of a video signal and its compensated video signal (e.g., one line of video content for a video frame), the deficiencies and compensation therefor as illustrated therein are applicable to these signals for the optical image entirely or in any selected part, whether described vertically,

horizontally and/or radially, or otherwise. That is, the compensation or other conditioning preferably is directed to ameliorate or correct differential picture brightness spatially.

Fig. 13(a) pictorially ~~represent~~ represents an optical image ~~wherein~~ having [[the]] differential, picture brightness. [[of an]] The optical image is brighter at its center 188 than at its periphery 190. The solid ~~portion~~ portions of [[line]] lines 192 depict a decreasing brightness of the optical image while the dashed portions of lines 192 depict ~~the less brightness as the bightness of the optical image drops of to the periphery 192 which is less bright~~ acceleration in the decrease of brightness toward the optical image's periphery 190. The shaded portion about the optical image's center 188 indicate brightness (uniform or otherwise) that exceeds a desirable level.

Fig. 13(b) pictorially ~~represent~~ represents an optical image ~~wherein~~ having [[the]] differential picture brightness. [[of an]] The optical image is brighter at its periphery 196 than at its center 188. The solid ~~portion~~ portions of [[line]] lines 200 depict a decreasing brightness of the optical image while the dashed portions of lines 200 depict ~~the less brightness as the brightness of the optical image is less bright at the center 198~~. acceleration in the decrease of brightness toward the optical image's center 198.

It is to be understood that, although Figs. 13(a) and 13(b) depict radially symmetric brightness functions (e.g., brightness levels vary but the variations are consistent among radii, with such variations being functions of disposition along a radius and not the radius' angle), such symmetry may be absent in practice. That is, brightness may be anywhere from less symmetric to partly or wholly asymmetric, including by varying either/both by radial disposition and angle. In addition, brightness may be characterized by variations in either/both horizontal and vertical dimensions associated with the optical image.

Fig. 14 is a pictorial representation of a line 204 representing the top portion of an envelope of a compensated video signal plotting the intensity as a function of distance "S" from the axis of the image 206. As shown by the line 204, the compensated video signal is amplified by a controlled device such as a controlled gain amplifier or variable gain amplifier to increase the

brightness of the output video signal to a level which is greater than the average of the differential brightness of the optical image due to the uneven illumination.

Before describing the operation of the schematic diagram of Fig. 16 (which is [[of the]] an embodiment of the video signal compensator 134 illustrated in Fig. 8), the following discussion relates to ~~the form of the basic~~ compensating waveforms that ~~are used in~~ associated with the video signal compensator ~~134 illustrated in Fig. 8, the following discussion relates to the form of the basic waveforms that are used in the video signal compensator for compensating differential picture brightness of an optical image due to uneven illumination.~~ . Although only sawtooth and parabolic waveforms are discussed in the following descriptions, it is recognized that either or both of these waveforms may be omitted, and that any number and variety of other waveforms may be employed (alone or in combinations with the sawtooth and/or parabolic waveforms), without departing from the principles of the invention. As an example, such other and combinations of waveforms may be employed when the differential picture brightness is characterized by partly or wholly asymmetry. As another example, the waveforms may be preset, so as, e.g., to correlate to and correct known deficiencies associated with medical imaging instruments and systems. As to this latter example, the preset waveforms preferably are brought into operation either manually or automatically, (e.g., by detection of the imaging instrument or one or more components of a system.

The video signal compensator comprises a device for generating a compensating signal substantially representing at least one parameter of a compensating waveform required for [[the]] addressing differential picture brightness of an optical image ~~to produce~~ toward producing a video signal representing an optical image having [[a]] substantially uniform brightness. In the schematic diagram of Fig. 16, the video signal compensator is an analog signal generating device.

The video signal compensator includes a sawtooth wave generator for generating a sawtooth waveform having a predetermined rising slope and a sawtooth wave generator for generating a sawtooth waveform having a predetermined falling slope. The sawtooth wave

generators described, as well as selected additional sawtooth wave generators, may be integral, grouped or separate, without departing from the principles of the invention.

Fig. 15(a) is a sawtooth waveform 210 having a predetermined rising slope and a controlled amplitude. Fig. 15(b) is a sawtooth waveform 212 having a predetermined falling slope and a controlled amplitude.

The video signal compensator also includes a parabolic wave generator for generating a parabolic waveform having a controlled amplitude and orientation. Plural parabolic wave generators may be provided, whether integral, grouped or separate, without departing from the principles of the invention.

Fig. 15 (c) is a parabolic waveform 214 having a controlled amplitude and orientation. If the orientation of the parabolic waveform is reversed, it is referred to as an "inverted parabolic waveform."

The amplitude and slope of [[the]] each sawtooth waveform and the amplitude and the orientation of [[the]] each parabolic waveform are adjusted ~~as required~~ to generate an acceptable compensating signal. In operation, a typical implementation of a video signal compensator provides an analog signal adder operatively coupled to the sawtooth wave generator and the parabolic wave generator adds the sawtooth waveforms and the parabolic waveform to produce a compensating signal. The compensating signal is used to compensate the video signal representing the optical image having differential picture brightness due to uneven illumination.

Referring now to the schematic, diagram of Fig. 16, the circuit is based on the use of two (2) quad operating amplifiers. In operation, the horizontal synchronizing signals of the composite video signal are applied to lead 220 and inverted by amplifier 224. If the horizontal synchronizing signals of the composite video signal are of proper polarity, then inversion of the signals will not be necessary. The output of amplifier 224 is applied as an input to amplifier 226 which is used as the sawtooth wave generator to generate a sawtooth waveform in the form of sawtooth waveform 210 of Fig. 15(a) having a predetermined rising slope and a controlled amplitude. The output of the

sawtooth wave generator 226 applies the sawtooth waveform to lead 230 which forms one side of a sawtooth waveform balance network 236. The output of the balance network 236 is adjusted as required to produce an acceptable balance using the sawtooth waveform by the variable pot, variable resistor or potentiometer depicted as balance network [[136]] 236. The output from balance network [[136]] 236 appears on lead 252.

In addition, the output of the sawtooth wave generator 226 applies the sawtooth waveform to lead 240 which is an input to amplifier 244. Amplifier 244, which essentially functions as a

sawtooth wave inverter, inverts the sawtooth waveform having a predetermined rising slope and a controlled amplitude to generate a sawtooth waveform having a predetermined falling slope and controlled amplitude in the form of sawtooth waveform 212 of Fig. 15(b). The output of the amplifier 244[[,]] applies the sawtooth waveform to lead 250 which forms the other side of [[a]] the sawtooth waveform balance network 236.

The output of the amplifier 244 is applied to input 254 of an amplifier 256 which functions as a parabolic wave generator. Amplifier 256[[,]] produces as an output a parabolic waveform ~~having a controlled amplitude and orientation~~ in the form of parabolic waveform 214 of Fig. 15(c) having a controlled amplitude and orientation. In the preferred embodiment, the parabolic waveform is an inverted parabolic waveform.

Lead 252, which is the output of the balance network [[136]] 236 is operatively connected to a summation terminal 260 which is an analog adder. The balance or mix of the sawtooth waveforms received by inputs 230 and 250, respectively, are controlled by the adjustment of the balance network 236. In addition, the output of the amplifier 256, which functions as a parabolic ~~waveform~~ wave generator, applies the parabolic waveform having a controlled amplitude and orientation to the summation terminal 260, to produce the horizontal component of the compensating signal.

The vertical portion of the compensating signal is generated as follows. The vertical synchronizing signals of the composite video signal [[is]] are applied to lead 270 and inverted by

~~Amplifier~~ amplifier 272. If the vertical synchronizing signals of the composite video signal are of proper polarity, then inversion of the signals will not be necessary. The output of amplifier 272 is an input to amplifier 274 which ~~issued~~ is used as the sawtooth wave generator to generate a sawtooth waveform in the form of sawtooth waveform 210 of Fig. 15(a). The output of the sawtooth wave generator 274 applies the sawtooth waveform to lead 280 which forms one side of a sawtooth waveform balance network 286. The output of the balance network [[302]] 286 is similarly adjusted by the variable pot, variable resistor or potentiometer ~~depicted as balance network 286 and the~~, which output appears on lead 302.

In addition, the output of the sawtooth wave generator 274 applies the sawtooth waveform to lead [[input]] 290 of an amplifier, 294. Amplifier 294, which essentially functions as a sawtooth wave inverter, inverts the sawtooth waveform having a predetermined rising slope and a controlled amplitude to generate a sawtooth waveform having a predetermined falling slope and controlled amplitude in the form of sawtooth waveform 212 of Fig. 15(b). The output of the amplifier 294, which also functions as a sawtooth wave inverter, applies the sawtooth waveform to lead 300 which forms the other side of [[a]] the sawtooth waveform balance network 286.

The output of the amplifier 294 is applied to input 304 of an amplifier 306 which functions as a parabolic wave generator.

Amplifier 306[[,]] produces as an output a parabolic waveform having a controlled amplitude and orientation in the form of parabolic waveform 214 of Fig. 15(c). In the preferred embodiment, the parabolic waveform is an [["]]inverted parabolic waveform.[["]]

Lead [[302 of]] 302, which is the output of the balance network 286, is operatively connected to a summation terminal 310 which is an analog adder. The balance or mix of the sawtooth ~~waveform~~ waveforms received by inputs 280 and 300, respectively, are controlled by the adjustment of the balance network 286. In addition, the output of the amplifier 306, which functions as a parabolic ~~waveform~~ wave generator, applies the parabolic waveform having a controlled amplitude and orientation to the summation terminal 310, or analog adder, to produce the vertical

component of the compensating signal.

The horizontal portion of the compensating signal appearing on the summation terminal 260 and the vertical portion of the compensating signal appearing on the summation terminal 260 are applied to summation terminal 316 which produces the compensating signal required to compensate the video signal ~~to represent the~~ toward such video signal representing an optical image having substantially uniform brightness. The compensating signal appearing on summation terminal 316 is applied as an input to controlled gain amplifier 330 which amplifies the compensating signal to ~~the desired~~ a selected level.

Amplifier 340 is unused. The output of the controlled gain amplifier 330 has a high impedance relative to the video signal to be compensated in the video signal processor, illustrated as 134 in Fig. 8. Therefore, the output of the amplifier 330 is applied to input 332 of a video driver 334 which produces a compensating signal on output 336 at a low impedance. Output 336 is then applied to the preamplifier stage of the video signal processor 134 of Fig. 8 as is well known to a person skilled in the art. ~~An adder~~ ~~Typically, an adder or other component~~ in the video signal processor 134 is used to add, multiply, mix, interpolate, extrapolate or otherwise apply together the compensating signal and video signal to produce the compensated video signal.

Based on the above description, it is readily apparent that the video signal compensator is a device for generating a compensating signal substantially representing at least one parameter of a compensating waveform ~~required for the differential picture brightness of an optical image to produce a compensating signal~~ facilitating production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from a video signal representing an optical image having differential picture brightness. For example, ~~the parabolic waveform would be used alone~~ if one of a sawtooth wave generator and a parabolic wave generator was used to practice the teachings of this invention, a compensating signal would be generated which compensates the video Signal to represent ~~at least an improved optical image having substantially uniform brighness.~~ an optical image having decreased differential picture

brightness (i.e., increased uniformity in brightness). In a preferred embodiment, both the sawtooth waveforms and the parabolic waveform are used to produce the compensating signal ~~used to compensate and uncompensated analog video signal to represent an optical image having substantially uniform brightness~~.

As described above, the compensating signal ~~is added to~~ typically is added, multiplied, mixed, interpolated, extrapolated or otherwise applied with the video signal ~~at the input of a video signal processor 134~~ to produce a ~~compensating~~ compensated video signal. The video signal ~~process~~ processing apparatus 128 preferably is responsive to the compensating signal by adjusting [[the]] gain both vertically and horizontally, e.g., by increasing the gain [[of]] applicable to the video signal representing that part of the optical image which is less bright than a reference [[and]] level and/or, e.g., by reducing the gain of the video signal representing that part of the optical image which is brighter than ~~a reference~~ the same or another reference level and, thereby, compensating the video signal to represent an optical image having a substantially uniform brightness.

It is understood that the compensated video signal may be subject to processing in addition to formatting. As an example, the compensated video signal may be processed to remove artifacts. It also may be processed so as to respond to signal saturation, as might occur when, during a medical procedure, a reflective medical instrument enters a portion of the target site characterized by an enhanced gain via a compensating signal. In that event, the enhanced gain typically would be reduced and, preferably, that reduction would be implemented on a dynamic basis.

~~In the preferred embodiment, the differential picture brightness~~ In a typical case, an optical image is brighter at its center than at its periphery. The video signal compensator ~~adder adds the sawtooth waveform~~, implemented according to Figure 16, adds, multiplies, mixes, interpolates, extrapolates or otherwise applies together one or more sawtooth waveforms and the parabolic waveform ~~and the video signal~~ (and, in some embodiments, the video signal or portion(s) thereof),

such waveforms being properly balanced and otherwise calibrated, to produce a compensating signal [which]. The compensating signal typically is employed within the video signal compensator or is applied as an input to a video signal processor ~~adjusting its gain~~ . So employed or applied, the compensating signal preferably adjusts the gain applicable to the video signal, e.g., both vertically and horizontally. This is accomplished, typically, by increasing the gain [[of]] applied to the video signal in to the sawtooth waveform representing the periphery of the optical image and by reducing the gain applied to the video signal in response to the parabolic waveform representing the center of the optical image, resulting in the video signal representing an optical image having a substantially flat brightness.

~~In the event that the differential picture brightness of~~ In another typical case, wherein an optical image is brighter at its periphery than at its center[[.]], ~~The adder adds the sawtooth waveform,~~ the video signal compensator typically adds, multiplies, mixes, interpolates, extrapolates or otherwise applies together one or more sawtooth waveforms and the parabolic waveform ~~and the video signal~~ (and, in some embodiments, the video signal or portion(s) thereof), such waveforms being properly balanced and otherwise calibrated, to produce a compensating signal. [[which]] The compensating signal typically is employed within the video signal compensator or is applied as an input to a video signal processor together ~~with a compensating signal producing~~ the video signal so as to produce a compensated video signal. The ~~compensated video signal is used to adjust~~ compensating signal, so employed or applied, preferably adjusts the gain of the video signal ~~processor~~, e.g., both vertically and horizontally. This is accomplished by decreasing the gain [[of]] applied to the video signal in response the sawtooth waveform representing the periphery of the optical image and by increasing the gain [[of]] applied to the video signal in response to the parabolic waveform representing the center of the optical image, resulting in said video signal representing an optical image having a substantially flat brightness.

Figures 1 through 16 disclose the elements or components of a preferred embodiment of a system for practicing this invention. The system includes an endoscope 30 having a proximal end

38 and a distal end 36. A light guide 72 is located within the endoscope and extends from the proximal end 38 to the distal end 36 of the endoscope 30. The light guide 72 has a light post 52 at its proximal end which is adapted to receive light energy from a light source 67 and to transmit the light energy from its distal end to illuminate ~~an operative~~ a target site.

In the alternative, the light guide 72 could be eliminated and an illumination source such as a light bulb could be located directly at the distal end 36 of the endoscope 30.

The endoscope includes an optical image transferring member, ~~included as part of element 76,~~ which includes, in one embodiment, image passing device 76 and which extends from the proximal end 38 to the distal end 36 of the endoscope. A light source 67 is operatively connected to the light post 52 to apply light energy to the light guide 72. A video sensor 68 is operatively coupled to the proximal end of the endoscope 30 for imaging an optical image having differential picture brightness due to uneven illumination.

A compensating apparatus is operatively coupled to the video sensor and typically includes a sawtooth wave generator for generating a sawtooth waveform having a predetermined rising slope[[,]] and/or a predetermined falling slope, and a controlled amplitude. In addition, the compensating apparatus includes a ~~parabola~~ parabolic wave generator for generating a ~~parabola~~ parabolic waveform having a controlled amplitude and orientation. [[An]] Typically, an adder is operatively coupled to the sawtooth wave generator[[,]] and the parabolic wave generator ~~and a video signal~~ for adding the sawtooth waveform and the parabolic waveform to produce a compensating signal which is used as ~~an input to a video signal processor adjusting its gain~~ to adjust the gain applied to the video signal, e.g., both vertically and horizontally. This is accomplished by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference, thereby compensating the video signal to represent an image having a substantially uniform brightness.

~~Also, the preferred embodiment of the endoscope includes a light guide 72 which is~~

~~a fiber optic light guide and the laparoscope having a fiber optic light guide independent of the distal end of the endoscope produces and optical image having a differential picture brightness which is brighter at its center than at its edges.~~

In the embodiment of Fig. 17, an optical image having differential picture brightness due to uneven illumination 398 is imaged directly or indirectly onto a [[CCD]] video sensor 400 (e.g., in the form of a CCD). The output from the video sensor 400 is an analog video signal which is applied to a preamplifier 402. The preamplified video signal is applied to an analog-to-digital converter 406. The video signal compensator in this embodiment is a part of a digital signal processing device shown by dashed [[lines]] box 410.

The digital signal processing device 410 includes a digital storage device ~~or freeze frame414 for storing~~ 414 (e.g., in the form of a freeze frame) a digital representation of the video signal having the differential brightness due to uneven illumination as received from the analog-to-digital converter 406. Concurrently, the digital video signal from the analog-to-digital converter 406 is applied to a digital signal processor 416 for digitally processing the digital signal representation of the video signal. The digital processor 416 produces a digital compensating signal representing at least one parameter of a compensating waveform ~~required for the differential picture brightness of an optical image to produce a video signal representing an optical image having a substantially uniform brightness.~~ facilitating production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from a video signal representing an optical image having differential picture brightness. The digital signal processor 416 digitally calculates the components of the compensating signal using a sawtooth waveform reference and a parabolic waveform reference in a process analogous to that of the analog process described above ~~for the analog processing, except however, the calculation is performed digitally~~. The output [[form]] from the digital signal processor 416 is a compensating signal in analog format having an illumination signal Y_o and color signal C_O. ~~Illuminates~~ Illumination signal Y_o appears on lead 424 and color signal C_O [[to]] appears on lead 426.

The video signal is stored in the digital storage device 414 for a predetermined period of time and is applied to a digital-to-analog converter 420. The output from the digital-to-analog converter 420 is the analog video signal representing the ~~output~~ optical image ~~390 delay~~ 398 delayed by a predetermined time period. The output from the digital-to-analog converter 420 appears on output 430.

The illumination signal Y_o on lead 424 is applied as an input to first adder 434. The color signal C_O on lead 426 is applied as an input to a second adder 438. The delayed uncompensated analog video signal on output 430 is applied to each of the first ~~inputs of the adders~~ adder 434 and second adder 438.

The analog output from the first adder 434 is in the form of a compensated illumination signal Y_m which appears on output lead 440. The analog output from the second adder 438 is in the form of a compensated color signal C_m which appears on output lead 442. [[The]] These output ~~video signal represents~~ signals represent the Optical image having substantially uniform brightness and is applied to ~~a device~~ an output device, such as that shown by 138 in Fig, 8.

In an alternative embodiment, the structures of Figure 17 may be otherwise operated to produce a compensated video signal. Such embodiment contemplates a learning mode and an operating mode. In the learning mode, the freeze frame 414 receives a video signal for characterizing the differential picture brightness. The freeze frame 414 processes the learning-mode video signal so as to identify digital compensation coefficients for each pixel of the frame. As an example, the coefficients may be calculated, as follows: a) determine a reference brightness for the learning mode frame(s) (e.g., an average brightness value across all or part of the frame, a median brightness value across all or part of the frame or otherwise) and b) dividing, for each pixel, the reference brightness by the pixel's actual brightness for the learning mode frame(s).

In a preferred embodiment, the learning mode provides for detection of flawed or otherwise unacceptable results from the learning mode. In the event of such detection, the learning mode preferably supports one or more default compensations. Such default compensations may be

variously implemented. Example implementations include: a) generating digital compensation coefficients that comprise a best fit (e.g., based on the learning mode data that appears to be without substantial flaws, at least to a threshold confidence); b) employing a previous set of compensation coefficients (e.g., as to all or as to part or parts of the optical image); c) bypassing compensation (e.g., as to all or as to part or parts of the optical image); and d) a combination of implementations, including of those implementation not listed above (e.g., selecting among previous sets of compensation coefficients to find a best fit and, if the best fit is deemed unacceptable, implementing a bypass).

In the operating mode, the compensation coefficients are processed via the DAC 420 to generate an analog compensating signal. Concurrently, the DSP receives a digital video signal from the ADC 406. The DSP processes the digital video signal and, via a digital-to-analog functionality, produces an analog illumination signal Y_o on lead 424 and an analog color signal C_o on lead 426. The compensating signal is applied (via adding, multiplying, mixing, interpolating, extrapolating or otherwise) with the illumination signal Y_o and with the color signal C_o, respectively at application components 434, 438. The application components 434, 438 produce compensated video signal, this signal comprising compensated illumination signal Y_m (on output lead 440) and compensated color signal C_m (on output lead 442).

Although Fig. 17 shows only one compensating signal, it is understood that more than one compensating signal may be generated. In particular, it is contemplated that separate compensating signals may be generated toward compensating, respectively, the illumination signal Y_o and the color signal C_o. Moreover, although Figure 17 shows compensation as to Y/C formatted video signals, it is understood that compensation may be applied to a video signal or signal of other formats. As examples, the compensation may be applied to composite video signals, color differential signals, RGB video signals, NTSC, PAL, SECAM or any other format, along or in combination(s).

In the embodiment of Fig. 18, the initial components are the same as described in Fig. 17 and include the optical image having differential picture brightness, due to uneven illumination 398 being imaged directly or indirectly onto a [[CCD]] video sensor 400. The output from the video sensor 400 is an analog video signal which is applied to a preamplifier 402. The preamplified video signal is applied to an analog-to-digital converter 406. The video signal compensator in this embodiment is a part of a digital signal processing device shown by dashed ~~lines 410~~ box 410'. The digital signal processing device 410' produces a compensating signal representing at least one parameter of a compensating waveform facilitating production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from the video signal representing an optical image having differential picture brightness.

At this point, the embodiment of Fig. 18 differs from that of Fig. 17. In the embodiment of Fig. 18, the digital signal processing device 410' includes a digital storage device ~~or freeze frame~~ 414 (e.g., in the form of a freeze frame) for storing a digital representation of the video signal having [[the]] differential brightness due to uneven illumination received from the analog-to-digital converter 406. Concurrently, the digital video signal from the analog-to-digital converter 406 is applied to ~~a programmable digital processor shown by dashed box 410' for digitally processing a digital representation of the video signal representing the differential picture brightness of the optical image due to uneven illumination. The digital signal processor 410' produces a digital compensating signal representing at least one parameter of a compensating waveform required for the differential picture brightness of an optical image to produce a video signal representing an optical image having a substantially uniform brightness. In this embodiment the programmable digital processor 410' includes~~ an 8 x 8 pixel matrix multiplexer/processor 450.

The video signal is stored in the digital storage device 414 for a predetermined period of time to enable the 8 x 8 pixel matrix multiplexer/processor 450 to digitally calculate the components of the compensating signal using a sawtooth waveform reference and a parabolic waveform reference in a process analogous to that of the analog process described above ~~for the analog~~

~~processing, except however, the calculation is performed digitally~~. The 8 x 8 pixel matrix multiplexer/processor 450 analyzes the brightness level of the optical image represented by the video signal on a bit-by-bit [[bases]] basis against a brightness reference to determine ~~the required~~ a compensating signal for the horizontal and vertical components thereof. The output of the 8 x 8 pixel matrix multiplexer/processor is a digital signal.

The output from the digital storage device 414 is applied to the 8 x 8 pixel matrix multiplexer/processor 450 where the digital video signal is compensated with the compensating signal generated by the 8 x 8 pixel matrix multiplexer/processor 450.

The output from the 8 x 8 pixel matrix multiplexer/processor 450 is applied to the digital signal processor 416 which produces a compensated analog video signal representing the ~~differential picture brightness~~ optical image having substantially uniform brightness. The digital techniques for performing this analysis are well known to persons skilled in the art.

In the embodiment illustrated in Fig. 18, the analog output from the digital signal processor 416 is in the form of a compensated illumination signal Y_m which appears on output lead 452 and a color signal C_m which appears on output lead 454. It is to be understood that, while the color signal may remain uncompensated, the color signal typically is also compensated.

In an alternative embodiment, the structures of Figure 18 may be otherwise operated to produce a compensated video signal. Such embodiment contemplates a learning mode and an operating mode. In the learning mode, the freeze frame 414 receives a video signal for characterizing the differential picture brightness. The freeze frame 414 processes the learning-mode video signal so as to identify digital compensation coefficients for each pixel of the frame. The coefficients may be calculated as described above for the alternative embodiment based on Figure 17.

In a preferred embodiment, the learning mode provides for detection of flawed or otherwise unacceptable results from the learning mode. In the event of such detection, the learning mode preferably supports one or more default compensations. Such default compensations may be

variously implemented. Example implementations include: a) generating digital compensation coefficients that comprise a best fit (e.g., based on the learning mode data that appears to be without substantial flaws, at least to a threshold confidence); b) employing a previous set of compensation coefficients (e.g., as to all or as to part or parts of the optical image); c) bypassing compensation (e.g., as to all or as to part or parts of the optical image); d) detecting pixels having sensitivity defects (e.g., individual pixels having hyper-, hypo- or no sensitivity), whether of individual or group(s) of pixels, so as to interpolate, extrapolate or otherwise treat such pixels isolated from other compensation (or other conditioning), and e) a combination of implementations, including of those implementation not listed above (e.g., selecting among previous sets of compensation coefficients to find a best fit and, if the best fit is deemed unacceptable, implementing a bypass).

In the operating mode, the pixel matrix multiplexer/processor 450 receives a digital video signal from the ADC 406. The multiplexer/processor 450 also receives the digital compensation coefficients from the freeze frame 414, which coefficients serve as a compensating signal in the digital domain. The multiplexer/processor 450 digitally adds, multiplies, mixes, interpolates, extrapolates or otherwise applies the coefficients to the video signal. As such, the multiplexer/processor 450 produces a compensated digital video signal which signal is applied to the DSP 416. The DSP formats the video signal so as to output compensated illumination signal Y_m (on output lead 452) and compensated color signal C_m (on output lead 454).

As to implementations supporting learning modes, it is recognized that, various advantages attach. As an example, such implementations tend to enhance correction of asymmetrical differential brightness. As another example, such implementations tend to enhance correction of dynamic variations in differential brightness, such as those that may result from rotation of an endoscope during a procedure. As yet another example, such implementations tend to enhance correction of variations in differential brightness developing over time, e.g., from the deteriorating performance of the endoscope, any components thereof, and/or any components of the system,

including one or more illuminators.

In smaller diameter endoscopes having a diameter at the distal end [[in]] on the order of about 5 mm or less, the video signal representing the optical image typically has (a) a waveform 460 illustrated by Fig. 19. In Fig. 19, the waveform 460 has a low level noise portion of the video signal shown as element 462 which appears before the ~~video information signal portion~~ picture information portion 464 of the video signal and (b) a low level noise portion of the video signal shown as element 466 which appears after the ~~video signal portion 464 representing the picture information~~ picture information portion 464. [[This]] These low level noise ~~portion~~ portions 462, 466 of the video signal 460 can be monitored by a sensing device for sensing and removing the noise to improve the video signal.

Fig. 20 illustrates a waveform 470 of the video signal from a small diameter endoscope illustrating the effects of the sensing device for sensing and removing the noise before and after picture information portion 474 of the video signal. In Fig. 20, the ~~portion~~ portions of the signal shown as 472 ~~before the information portion of the signal 474 has~~ and 474, respectively before and after the picture information portion 474, have the noise removed therefrom. The picture ~~portion of the video~~ information portion ~~signal~~ 474 is substantially the same as the picture information ~~signal~~ portion 464 of Fig. 19. ~~Also, in Fig. 20, the portion of the signal shown as 476 after the information portion of the signal 474 has the noise removed therefrom. In this manner, the picture information represented by the portion of the signal 474 represents the definitive picture signal.~~

In [[the]] a preferred embodiment, the sensing device for sensing and removing the noise is in the form of a blanking circuit 480 as illustrated by Fig. 21. The signal appearing on input 482 to the blanking circuit 480 is essentially in the form of the waveform 460 shown in Fig. 19. The signal appearing on the output 484 of the blanking circuit is essentially in the form of the waveform 470 shown in Fig. 19. One example of a sensing device that can be used in such a blanking circuit is a ~~Schmidt~~ Schmitt trigger which ~~require~~ requires that a certain threshold voltage level be reached by the video signal before the amplifier receives the input video signal. Of course, any known

electrical system or circuit for sensing and removing the noise is envisioned to be within the teachings of this invention.

The present invention includes a method for compensating for differential picture brightness of an optical image due to uneven illumination. The method comprises the steps of: (a) generating with a compensating signal generating device a compensating signal substantially representing at least one parameter of a compensating waveform ~~required for the differential picture brightness of an optical image to produce a video signal representing an optical image having a substantially uniform brightness~~ to facilitate production of a compensated video signal (i.e., a video signal representing an optical image having substantially uniform brightness) from the video signal representing an optical image having differential picture brightness; and (b) ~~adding with an adder~~ adding, multiplying, mixing, interpolating, extrapolating or otherwise applying together with an adder, multiplier, mixer, interpolator, extrapolator or other application component operatively coupled to the compensating [[video]] signal generating device and a video signal the compensating signal and the video signal to produce a ~~compensating signal which is used as an input to a video signal processor to adjust its gain~~ compensated video signal. The compensating signal preferably is employed to adjust the gain applied to the video signal. As an example, the compensating signal applies both vertically and horizontally by increasing the gain of the video signal representing that part of the optical image which is less bright than a reference and reducing the gain of the video signal representing that part of the optical image which is brighter than a reference, thereby compensating said video signal to represent an optical image having a substantially uniform brightness.

In an application where the differential picture brightness of an optical image is brighter at its center than at its edges, the method ~~step of adding~~ produces as an output signal a video signal having its gain both vertically and horizontally compensated by increasing the gain of the video signal in response to the sawtooth waveform representing the edges of the optical image and reducing the gain of the video signal in response to the parabolic waveform representing the center

of the optical image, thereby compensating said video signal to represent an optical image having a substantially flat brightness.

In an application where the differential picture brightness of an optical image is brighter at its edges than at its center, the method ~~step of adding~~ produces as an output signal a video signal having its gain both vertically and horizontally compensated by decreasing the gain of the video signal in response to the sawtooth waveform representing the edges of the optical image and increasing the gain of the video signal in response to the parabolic waveform representing the [[edges]] center of the optical image, thereby resulting in said video signal representing an optical image having a substantially flat brightness.

Where the method is an analog process, the step of ~~adding includes~~ adding, multiplying, mixing, interpolating, extrapolating or otherwise applying may be accomplished using a compensating signal generating device which is an analog signal generating device for generating the compensating signal. Similarly where the method is a digital process, the step of ~~adding includes~~ adding, multiplying, mixing, interpolating, extrapolating or otherwise applying may be accomplished using a compensating signal generating device which is an digital signal processing device for generating the compensating signal.

If it is desired to raise the brightness level of the compensated video signal, the method may further include[[s]] the step of[[: (a)]] increasing ~~with a control device operatively coupled to the adder~~ the brightness [[of]] associated with the output video signal to a level which is greater than the average of the differential brightness of the optical image due to the uneven illumination. Similarly, the brightness associated with the output video signal may be adjusted (pre- or post-compensation) so as to have a brightness at a selected level below that average, or above or below a reference, or based on some selected calculus. To accomplish this, a control device may be employed, e.g. one operatively coupled to the adder, multiplier, mixer, interpolator, extrapolator or other application component. For impedance matching, the method may further include[[s]] the step of[[: (a)]] applying, with a driver amplifier operatively coupled to the adder, the output video

signal to a video signal processor at a low impedance.

In [[the]] a preferred embodiment, the method includes the use of a compensating signal generating device which is an analog signal generating device for generating the compensating signal. The method ~~further~~ preferably comprises the steps of: (a) generating with a sawtooth wave generator a sawtooth waveform having at least one of a predetermined rising slope, a predetermined falling slope and a controlled amplitude, (b) generating with a ~~parabola~~ parabolic wave generator a parabolic waveform having a controlled amplitude and. orientation; and (c) ~~adding with an analog adder~~ adding, multiplying, mixing, interpolating, extrapolating or otherwise applying together, using an analog adder, multiplier, mixer, interpolator, extrapolator or other application component, one or more of the sawtooth ~~waveform,~~ and the parabolic waveform ~~and the video signal~~ (and, in some embodiments, the video signal or portion(s) thereof) to produce the ~~compensating~~ compensated video signal.

Although [[the]] a preferred embodiment of the present invention is ~~used in~~ a medical laparoscope having a fiber optic light guide, the video signal compensator can be used with any optical system where a light source having a non-uniform or uneven characteristics is used to illuminate an operative site or inspection area providing an optical image having ~~differentiated~~ differential picture brightness due to [[the]] uneven illumination. The light source may be located intermediate the endoscope or at the distal end of the endoscope.

It is also envisioned that the teachings of the present invention can be used for industrial applications. For example, borescopes are used to inside the inspect the interior stages of jet engines Typically, the optical image produced by a borescope is imaged directly on a video camera. The video signal compensator disclosed and taught herein can be used for such industrial applications. Further, ~~person~~ persons skilled on the art can identify other applications where the uneven brightness of an optical image can be compensated to produce a substantially uniform brightness level. It is envisioned that this invention can be used for such applications.

Turning to Figure 22, depicted is a high level block diagram of a medical imaging instrument or system 2200, in accordance with the invention. The medical instrument or system 200 comprises illuminators 2212, 2212a, an image acquisition component 2214, an output component 2216 and a conditioning component 2218.

In Figure 22, a target site 2210 is illuminated by illuminator 2212. As previously described, the target site 2210 comprises an operative site and/or an inspection area and the illuminator 2212 comprises one or more of light sources, light guides and the like. The target site 2210, for the purposes of the following description, has an associated target image. A target image is a representation of the target site, the representation being an optical, electronic or other signal, that signal being formatted consistent with signals for driving one or more relevant output devices, photonic devices or interface technologies (the latter terms being defined below).

Generally, the concept of a target image expresses a goal selected for achievement. As an example, in the context of a video display, a target image may be selected that correlates to a display image of the target site, the display image being displayed on a monitor, and wherein a) the target site is illuminated without deficiency (e.g., without unevenness) and b) no other component of the imaging instrument and system (including any video sensor, image transferring structure and monitor) contributes deficiencies in the acquisition, transmittal, processing and display of the image.

The target image generally is associated with selected parameters, qualities and/or characteristics. These parameters, qualities and/or characteristics may extend to the entire image or only to parts thereof (e.g., the target image may comprise a key area that, like a spotlight, draws the attention of the conditioning component). As an example, the target image may be characterized in its omission of differential picture brightness associated with uneven illumination of the target site.

It is understood that a target image may be selected that falls short (and, perhaps, falls substantially short) of being a perfect image of the target site. As an example, the target image

may be flawed significantly as to other than the selected parameters, qualities and/or characteristics. As another example, the target image may engender a compromise among one or more parameters, qualities and/or characteristics, with or without a compromise as to one or more other parameters, qualities and/or characteristics (e.g., a best fit).

In a specific case, a target image may be selected to correlate to a display image of the target site wherein the target site is illuminated unevenly. In this case, the target image is selected with attention to parameters, qualities and/or characteristics relevant to target site illumination. Moreover, the target image may or may not be selected with attention to other parameters, qualities and/or characteristics. (Such other parameters, qualities and/or characteristics, if any, otherwise may or may not have --or may be substantially without-- deficiencies.)

So subject to uneven illumination, this case's target image is characterized by differential picture brightness. The differential picture brightness may, however, be trivial in that spatial variations in brightness below a detection threshold are understood to be undetectable to the human eye. The detection threshold is subject to various factors, including factors relating to the output device (e.g., a printer, a display, the presentation area and dot pitch), the video sensor (e.g., its dynamic range), the site illumination (e.g., the intensity and energy distribution), ambient lighting, the quality and aperture of applicable optics (e.g., of an endoscope), the medical procedure, and the quality of the human eye (specifically or generally), many of which factors are quantifiable through empirical analysis or otherwise.

Accordingly, a target image may be selected which has associated therewith undetectable or detectable differential picture brightness. In the undetectable case, the target image effectively is characterized by the absence of associated differential picture brightness, whether the selected target image correlates to a display image having differential picture brightness at, under or well under the detection threshold. In the detectable case, the target image typically is selected in connection with efforts to reduce differential picture brightness in imaging (i.e., although the flaw remains, it or its impact has been ameliorated). In this latter case, the target image preferably is

selected so that the differential picture brightness, while detectable, is acceptable under selected criteria. As an example, the target image may be selected notwithstanding detectable differential picture brightness, provided that flaw is insufficient to impede an applicable medical procedure or otherwise to engender a non-trivial problem in imaging and use.

Moreover, the detectable case explicates the nature of the compensated video signal of previously described camera embodiments. In such embodiments, the cameras produce compensated video signals which video signals represent optical images having substantially uniform brightness, as contrasted with uncompensated video signals representing optical images having differential picture brightness. In such discussions, the term "substantially uniform brightness" generally corresponds to the employ of a target image which itself corresponds to elimination of differential picture brightness, to reduction of differential picture brightness below the detection threshold, or to having a detectable differential picture brightness that, as determined under the circumstances, is acceptable under selected criteria.

While the descriptions above focus on target images that correlate to display images, the correlation may be selected respecting other output devices, photonic devices or interface technologies, with or without a display device. In any case, a target image is a representation of the target site, the representation being an optical, electronic or other signal of appropriate formatting. The illuminator 2212 may be variously implemented. In a medical instrument such as an endoscope, as previously described, the illuminator 2212 may be disposed internal to the endoscope's housing. At the same time, the illuminator 2212 may be otherwise disposed, including external to the endoscope (in such case, the illuminator 2212 generally may not be considered a component of the instrument). In a medical system, the illuminator 2212 may be implemented so that the illuminator 2212 is integral with the imaging instrument or separate therefrom.

Moreover, plural illuminators 2212 may be employed, as indicated by second illuminator 2212a in Figure 22. In such case, one or more illuminators 2212, 2212a may be integral with the

imaging instrument and/or one or more illuminators 2212, 2212a may be external to such instrument, or some combination of integral and external illuminators may be used.

As previously described, the illuminators 2212, 2212a may direct selected illuminating frequencies onto the target site 2210. While white light is typical, it may be supplemented with, or substituted by, other frequencies outside the visible spectrum. These supplemental/substitute frequencies may be variously implemented, particularly when plural illuminators 2212 are employed. The supplemental/substitute frequencies may be variously employed, including, as examples, toward enhancing acquisition, conditioning and/or output of an image (as described below) or toward recognition of the target site, portion(s) thereof and/or anomalies therein (such recognition may also be employed in the enhancing process).

In any case, the illuminators 2212 generally provide deficient illumination. In particular, illuminators 2212 typically subject the target site 2210 to uneven illumination.

The image acquisition component 2214 generates one or more acquired images of the target site. An acquired image may be an optical, electronic (e.g., video) or other signal, or a combination thereof. An acquired image generally results from illumination of the target site 2210, as provided by the illuminators 2212.

The image acquisition component 2214 may be variously implemented. The image acquisition component 2214 typically comprises one or more video sensors, optical image transferring structures, and other mechanical, optical, electronic, opto-mechanical, electro-mechanical, and electro-optical components.

The image acquisition component 2214 may be variously disposed. The disposition depends, among other things, on its implementation and, in some cases, on the implementation of the output component 2216. The disposition also depends on whether the component 2214 is implemented as part of a medical instrument or as part of a medical system. As an example, if the image acquisition component 2214 is implemented as a CCD without an optical image transferring structure, the component 2214 typically is disposed at or adjacent the distal tip of an endoscope,

so as to generate a video signal that, via electrical connectors, is provided to either/both the conditioning component 2218 and the output component 2216. As another example, however, if the image acquisition component 2214 is implemented to include a CCD which is disposed away from the endoscope's distal tip or remotely from the endoscope itself, the image acquisition component 2214 typically will be implemented also to include an optical image transferring structure, such structure disposed so as to receive the optical image of the target site and provide that image to the CCD so that the CCD may generate one or more acquired images. (Indeed, in such latter case, the image acquisition component 2214 generates at least two acquired images -- one being an optical signal of the structure and another being an electronic signal from the CCD.)

The output component 2216 generates one or more output images, the output images being available on output 2226. An output image may be an optical, electronic (e.g., video) or other signal, or a combination thereof. The output image preferably correlates to, or achieves substantial correlation to, the target image. As an example, if the target image is selected so as to have differential picture brightness that is undetectable over some portion of an image, the output image preferably achieves undetectability over that entire portion or over substantially all of the portion and, where that undetectability is not achieved respecting that portion, the output image preferably achieves substantial undetectability. In any case, correlation may be deemed present provided that the agreement of the output image with the target image is sufficient to preclude any significant impediment to the use of the instrument/system/method (including respecting any applicable medical procedure) and does not engender a non-trivial problem in imaging or related thereto.

The output component 2216 is variously implemented. Typically, the output component 2216 comprises a display device (e.g., as previously described, flat panel display technology, light valve technology, tube technology or otherwise), a printing device, a storage device, a networking device or some other output device. The output component 2216 may also comprise one or more optical lenses, lens groups, fiber optics (e.g., a fiber optic bundle having one or more optical

fibers), or other photonic device. The output component 2216 may also comprise an interface or other connection technologies (all referred to sometimes hereinafter as "interface technology"), including to or with any one or more of such output devices and/or photonic devices. The output component 2216 may also comprise a combination of output devices, of photonic devices, of interface technology, or any groups of same.

As an example, the output component 2216 may be implemented integrally with an endoscope. The output component 2216 may comprise an interface which directs output images (e.g., as formatted or unformatted video signals) to a remote output or photonic device 2228 (e.g., a display device). In such case, the output/photonic device 2228 typically is considered to be part of the medical system, but not part of the endoscope itself. Moreover, as previously described with respect to Figures 1 and 2, the output component 2216 may be operatively coupled to the endoscope, but considered separate therefrom.

The output component 2216 is variously disposed. The disposition depends, among other things, on its implementation and, in some cases, on the implementation of the image acquisition component 2214. The disposition also depends on whether the component 2216 is implemented as part of a medical instrument or as part of a medical system. As an example, if the output component 2216 comprises a monitor or a head mounted display, that component 2216 is likely to be disposed remotely from an endoscope. As another example, the output component 2216 may be integral with the endoscope, particularly if implemented as a small display device (e.g., a miniature LCD-on-silicon display and associated optics, all integrated as the endoscope's eyepiece).

The conditioning component 2218 may also be variously implemented. Generally, the conditioning component 2218 provides for selective conditioning of one or more acquired images, one or more output images or one or more intermediate images (such intermediate images typically being derived from acquired and output images) or combinations of same. To illustrate, if the image acquisition component is implemented to generate acquired images comprising optical

and electrical signals, the conditioning component generally is implemented so as to provide for selective conditioning of both. Similarly, if the image output component is implemented to generate output images comprising optical and electrical signals, the conditioning component generally is implemented so as to provide for selective conditioning of both. In either such case, it is preferred that the conditioning component provides appropriate conditioning, e.g., conditioning appropriate to the respective image signal and to the respective image output component.

Although the conditioning component may apply conditioning to various images, the conditioning component generally is directed to enhance correlation of the output image to the target image. In a preferred embodiment, the conditioning component selectively reduces differential picture brightness across all or selected portions of the output image. In another preferred embodiment, the target image has an associated energy profile and the conditioning component conditions so as to enhance correlation of the energy profile of the output image to energy profile of the target image. Generally, the conditioning is performed in connection with and to improve performance in an applicable medical procedure.

The conditioning component provides for conditioning by (i) selectively processing all or selected portions of at least one of the acquired image, the output image and the intermediate image or (ii) selectively controlling at least one the image acquisition component and the image output component. In the first case, the conditioning component generally provides directly for processing of the images, e.g. in the conditioning component itself. As an example, in the above camera embodiments, the conditioning component is sometimes implemented as or within the video signal compensator, which compensator not only generates a compensating signal, but typically applies that signal to the video signal, so as to generate a compensated video signal.

In the second case, the conditioning component provides indirectly for processing. To illustrate, the conditioning component may generate control signals that direct operation of a digital component or may generate analog signals that control (e.g., via gain circuits, active filters, etc.) the performance of other components' processing the applicable acquired, output or intermediate

signal. As an example, where the image acquisition component has an acquisition area and has brightness sensitivity that is controllable as a function of acquisition area position, the conditioning component may be implemented to condition the acquired image by selectively controlling the brightness sensitivity of the image acquisition component. In another example, where the image output component has a output space and has brightness sensitivity that is controllable as a function of position in the output space, the conditioning component may be implemented to condition the output image by selectively controlling the brightness sensitivity of the image output component. The output space tends to be particular to the applicable output device, photonic device or interface technology (e.g., an output image that drives a monitor may have an output space correlating to the geometries of the monitor's display area).

It is also understood that the conditioning component may be implemented to provide for conditioning through a combination of such selective processing and controlling.

The conditioning component effectuates such processes or controls via selected signal processing. The signal processing may be conducted in the analog domain, the digital domain or in some combination thereof. The signal processing typically includes one or more of the following: amplification, attenuation, filtering, mixing, adding, multiplying, interpolating, extrapolating, phase shifting and frequency shifting. The signal processing may be applied to all or selected portions of at least one of the acquired image, the output image and the intermediate image.

Moreover, the signal processing typically varies across the acquired, output and intermediate images. As an example, the signal processing may be directed to increasing the brightness in some parts of an image while decreasing it in others. These increases and decreases may or may not have symmetry, or may have portions of symmetry or asymmetry, across an image.

The conditioning component preferably is responsive to the target image. That is, the conditioning component preferably is implemented to condition the acquired, output and/or

intermediate images as to the parameters, qualities and/or characteristics associated with the target image. To do so, the conditioning component typically provides for conditioning based on one or more calibrations (see, e.g., the learning modes of the alternative embodiments described above with reference to Figs. 17 and 18). Such calibration can be variously implemented, particularly in the context of a medical procedures. Example calibrations include: calibration previous to a medical procedure; manual calibration performed one or more times during a medical procedure; automatic calibration performed at regular intervals during the medical procedure; automatic calibration performed at intervals during the medical procedure based on selected triggering events; and dynamic calibration performed during the medical procedure.

Calibration may also be responsive to empirical information relevant to the medical procedure. As an example, calibration may be responsive to the detection threshold associated with differential picture brightness. Accordingly, the calibration may be directed to identify variations in performance relative to the detection threshold (e.g., whether the variations are detectable), and to provide for conditioning based thereon.

The conditioning component 2218 may be variously disposed. The disposition depends on whether the component 2218 is implemented as part of a medical instrument or as part of a medical system. As an example, the conditioning component 2218 may be integral, in whole or part, with either the image acquisition component 2214 or the image output component 2216. As another example, the conditioning component 2218 may be integral, in whole or part, with both the image acquisition component 2214 and the image output component 2216. In this latter example, the image acquisition component 2214, the image output component 2216, and the conditioning component 2218 may be integrated in a medical imaging instrument, such that the image output component 2216 is an interface technology which connects the medical imaging instrument with, separate from the medical imaging instrument, at least one output device, photonic device and interface technology.

The output component 2216 preferably is coupled with the image acquisition component 2214. Depending on the implementation of the conditioning component 2218, these components 2216, 2214 may be coupled directly (via coupling 2220), indirectly (via the conditioning component 2228), or both. If coupled directly, the output component 2216 preferably receives acquired images via the coupling 2200. If coupled indirectly, the output component 2216 may receive acquired images from the conditioning component 2218 (via coupling 2224), which acquired images may be wholly or partially conditioned, or not conditioned at all. If the acquired images are partially conditioned or not conditioned, the output component 2216 preferably also receives appropriate conditioning signals from the conditioning component 2218, such conditioning signals providing for conditioning of the acquired, output or intermediate images within the output component 2216. Moreover, such conditioning signals may be provided via output 2226 to other output devices/photonic devices/interface technologies, so as to control conditioning of acquired, output and/or intermediate image received or generated therein.

The invention also contemplates a method for use in imaging a target site in a medical procedure. In such method, the target site is subject to deficient illumination. Moreover, the methods responds to the target site having associated therewith a target image, that target image being selected respecting the deficient illumination. The method includes the steps of generating an acquired image of the target site, generating an output image of the target site, and conditioning at least one of the acquired image, the output image and an intermediate image. The method preferably provides for enhanced correlation of the output image to the target image. In particular, the method provides for conditioning to selectively reduce differential picture brightness across all or selected portions of an output image. The method contemplates operations in either/both the analog and digital domains.

The method contemplates conditioning provided by at least one of (i) selectively processing all or selected portions of at least one of an acquired image, an output image and an intermediate image, (ii) selectively controlling at least one of the generating of an acquired image and the

generating of an output image, and (iii) a combination of such processing and controlling. In such processing/controlling, the method contemplates conditioning by providing selectively for at least one of amplification, attenuation, filtering, mixing, adding, multiplying, interpolation, extrapolation, phase shifting and frequency shifting to all or selected portions of at least one of an acquired image, an output image and an intermediate image.

As an example, the method contemplates conditioning by controlling the generating of an acquired image and, in the specific case where an acquisition area has a brightness sensitivity that is controllable as a function of the acquisition area position, by selectively controlling the brightness sensitivity respecting the acquisition area position. As another example, the method contemplates conditioning by controlling the generating of an output image and, specifically in the case where an output space has a brightness sensitivity that is controllable as a function of position in the output space, by selectively controlling the brightness sensitivity respecting the output area position.

Because an acquired image may be generated as an optical signal and/or as an electrical signal, the method contemplates providing conditioning of either of both of these signals. Similarly, because an output image may be generated as an optical signal and/or as an electrical signal, the method contemplates providing conditioning of either of both of these signals.

The method preferably is responsive to the target image. That is, the method preferably is implemented to provide conditioning of the acquired, output and/or intermediate images as to the parameters, qualities and/or characteristics associated with the target image. To do so, the method preferably provides for conditioning based on one or more calibrations (see, e.g., the learning modes of the alternative embodiments described above with reference to Figs. 17 and 18). Such calibrating can be variously implemented, particularly in the context of a medical procedures. Example approaches for calibrating include: calibrating previous to a medical procedure; manually calibrating, in particular performed one or more times during a medical procedure; automatically calibrating, in particular performed at regular intervals during the medical procedure; automatically calibrating, in particular performed at intervals during the medical

procedure based on selected triggering events; and dynamically calibrating performed during the medical procedure. Calibrating may also be responsive to empirical information relevant to the medical procedure (e.g., the detection threshold associated with differential picture brightness).

As previously described, the invention also contemplates a medical system wherein the target site is illuminated, at least in part, using frequencies other than visible light. These frequencies may be variously employed, including, as examples, toward enhancing acquisition, conditioning and/or output of an image (as described below) or toward recognition of the target site, portion(s) thereof and/or anomalies therein (such recognition may also be employed in the enhancing process). As examples, the illumination includes ultrasonic radiation and/or electro-magnetic radiation in the infrared and/or x-ray spectrums. Based on reflections, absorptions and/or transmissions of that or other such radiation, the image acquisition component preferably generates an acquired image. That acquired image may be in substitution for or supplemental to an acquired image generated from illumination in the visible spectrum. In a particular embodiment, the conditioning component provides for selective conditioning of at least one of an acquired image, an output image and an intermediate image based on the radiation-based acquired. At the same time, the conditioning component typically conditions on bases other than the radiation-based acquired image.

Persons skilled in the art will recognize the foregoing description and embodiments are not limitations, but examples. It will be recognized by persons skilled in the art that many modifications and variations are possible in the details, materials, and arrangements of the parts and steps which have been described and illustrated in order to explain the nature of this invention, and that such modifications and variations do not depart from the spirit and scope of the teachings and claims contained herein.